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EDITOR

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THE RELATION OF DEEP-SEATED FAULTS TO THE SURFACE STRUCTURAL FEATURES OF CENTRAL MONTANA[1]

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INTRODUCTION

This study has been undertaken partly because the geology of Montana is of immediate interest to many petroleum geologists, and partly because it offers an unusually favorable opportunity to study the operation of great deformational forces and to test the extent to which subsurface conditions and general structural relationships can be predicted from a quantitative study of the geologic structure exhibited by the surface rocks of a large area. Such a study of land areas requires the construction of a structure-contour map, as the ordinary areal geologic map fails to give a definite idea of the relative magnitude and shape of its several structural features. Although such a contour map cannot afford conclusive evidence as to subsurface structural conditions unless supported by the evidence of test drilling, yet it may furnish the best clues available both as to the mode of origin and interrelationship of the various visible structural features of a region and may also indicate the divergences in structure between the deeper seated rocks and those relatively near the surface.

[1] Published by permission of the Director, U.S. Geological Survey.

Thanks are hereby tendered to Mr. David White, and to Mr. F.L. Ransome, of the United States Geological Survey, for their very helpful and suggestive criticism of this paper.

RELATION OF CENTRAL MONTANA TO CORDILLERAN STRUCTURE

The accompanying sketch map (Fig. 1) shows the relative position of some of the major structural features of the Cordilleran belt both with respect to one another and to those of central Montana.

As most readers will recall, the continuous mountain chain of the Canadian Front Range consists of the uplifted edge of a great fault block overthrust eastward, which is separated from the relatively level strata of the Great Plains province by a narrow belt of intensely faulted and folded rocks. In central Montana the main Front Range of the Rockies loses its continuous linear character and breaks up into a number of minor ranges. Coincident with this dispersion of the main Cordilleran backbone, a number of local uplifts and short detached ranges rise from the plains to the east, and it is not until Colorado is reached that the Rockies again reunite into a continuous range rising from the western edge of the Great Plains.

The great thrust fault which lies below the Canadian Front Range has been traced southward, as the Lewis overthrust, as far as the southern limit of Glacier National Park, and the zone of imbricated structure lying east of the main thrust has been followed along the mountain front nearly to the Missouri, indicating the continuance of thrusting at least that far. Important thrust faults have been reported at Phillipsburg by Calkins and Emmons,[1] and a considerable overthrust near Lombard has been described by Haynes.[2] It is also known that the great uplifted block of the Yellowstone Park—Beartooth Plateau is bounded, at least on

[1] F. C. Calkins, and W. H. Emmons, *U. S. Geol. Survey Atlas*, Phillipsburg folio (No. 196) (1915), p. 18.

[2] W. P. Haynes, "The Lombard Overthrust and Related Geological Features," *Jour. Geol.*, Vol. XXIV (1916), pp. 269–90.

its southeast side, by a thrust fault[1] probably closely related in origin to the great Heart Mountain thrust of the western Bighorn

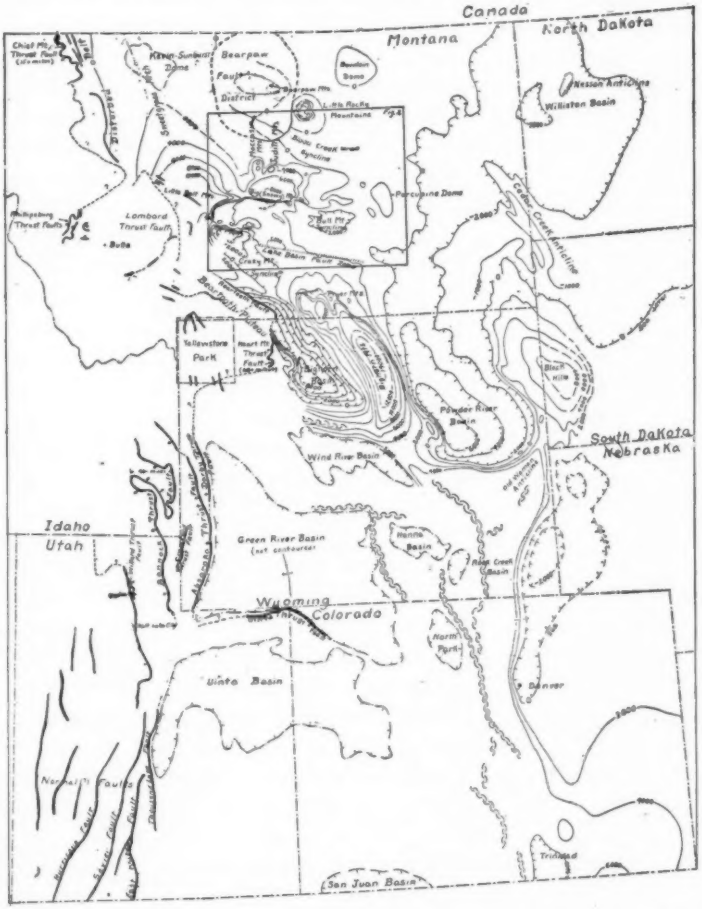


FIG. 1.—Structural sketch map showing position of central Montana area with reference to known thrust faults of the eastern Cordillera.

[1] C. L. Dake, "The Heart Mountain Overthrust," *Jour. Geol.*, Vol. XXVI (1918), p. 52.

Basin, which is credited with a horizontal displacement of at least 28 miles.[1]

Great thrust faults are also known to exist in western Wyoming, southeastern Idaho, northeastern Utah, and northwestern Colorado. The relationships of these several faults, one to the other, have not been established, but the continuity of the mountain ranges of the region, the relative topographic position of the several terranes involved, and the observed magnitude of the horizontal displacements, indicate that these faults have a common origin and that they are parts of a continuous major fracture.

Central Montana is interesting, therefore, as the region where the relatively simple overthrust of the Canadian Front Range gives place to more complex structural conditions, probably because the edge of the overthrust sheet there impinged against older east-west uplifts and was disrupted by them. The location of the Boulder batholith at the point of convergence of two sets of mountain trends and the unusual mineralization of the Butte district are presumably further indications that the main Rocky Mountain deformation was modified in the vicinity of Butte by structural factors not present in the Canadian Front Range area.

From the evidence cited by Lindgren[2] and Ransome[3] and from that afforded by the sedimentary rocks of Montana it appears that the waves of deformation and intrusion which began on the Pacific Coast in Upper Jurassic time affected areas progressively farther and farther to the east, but were not vigorously active in the Front Range areas until Upper Cretaceous time. During the late Cretaceous, however, Montana and Wyoming must in many important respects have presented a parallel to conditions now existent in the East Indies as described by Brouwer.[4] There the depressed

[1] D. F. Hewett, "The Heart Mountain Overthrust, Wyoming," *Jour. Geol.*, Vol. XXVIII (1920), p. 554.

[2] Waldemar Lindgren, "The Igneous Geology of the Cordilleras and Its Problems," *Problems of American Geology*, New Haven, Yale Univ. Press (1913), pp. 234–86.

[3] F. L. Ransome, "The Tertiary Orogeny of the North American Cordillera and Its Problems," *Problems of American Geology*, New Haven, Yale Univ. Press (1913), pp. 287–376.

[4] H. A. Brouwer, "The Horizontal Movement of Geanticlines and Their Fractures Near the Surface," *Jour. Geol.*, Vol. XXIX (1921), pp. 560–77.

area between the Asiatic and the Australian continents shows roughly concentric mountain arcs, visible as island chains and separated by deeps in the sea floor. Some of these islands give surface evidence of intense compression and thrust faulting, comparable to that exhibited in western Montana and Wyoming, and the Bighorn–Big Snowy and the Black Hills–Porcupine dome—Little Rocky lines may well have presented similar though less pronounced island arcs during Jurassic and Cretaceous time. In an article referred to by Professor Brouwer in his paper it had been suggested that the island chains are the products of folding at great depth under compression less intense than that productive of thrusts nearer the surface. In the writer's opinion such uplifts as the Bighorns and Black Hills are produced not by simple folding under compression or by the isostatic adjustment of areas of deficient mass, but are the products of a combination of the two processes, in which the relative plasticity of the earth's shell is quite as important a factor as is its rigidity within limited areas. Given an initial elevation in the Yellowstone Park region induced by compressive forces directed eastward, there needs must have been a contemporaneous depression of a trough (Bighorn Basin) to the east under the oblique downward thrust of the uplifted mass. The tangential forces producing the Yellowstone Park uplift would to some extent have affected areas farther to the east. The elastic bending stresses caused by the weight of the newly formed upfold, though progressively diminished outward from the fold by the partial plasticity of the earth's crust, would also help to produce a series of structural waves quite similar to those set up in unconsolidated sediments subjected to unequal loading. The distance from trough to crest of a given wave would necessarily be less than the distance within which isostatic adjustment becomes complete.

A series of crests, such as that presented by the Beartooth Plateau–Bighorn–Black Hills uplifts having been initiated by the compression applied in the Yellowstone Park region and by the unequal loading produced by this compressive action, would tend to continue to rise with reference to the adjacent synclines as a result of several causes. In so far as the crests were induced by loads applied to the earth's crust at some distance they would

become subjected to tensional stresses decreasing the load upon the rocks beneath them, and as a result these incipient anticlines would become loci of decrease in density and of magma development in their subjacent rocks. The upward rise and hydrostatic lift of the plastic or magmatic masses under such subsequent tangential compression as might be applied and the erosional shift of material from the crests to the troughs, producing re-elevation under isostatic adjustment, would both cause continued growth of the arches, as would the decreased density of the rocks beneath them. Contributory tangential thrust would also produce the lack of symmetry apparent in the Bighorn and Black Hills uplifts. This interpretation may suggest the relative rôles of tangential compression and vertical uplift in mountain elevation, a question several times raised in the symposium on isostasy contained in the June, 1922, number of the *Bulletin of the Geological Society of America*.

The shift in general trend of the Rocky Mountains occurring in west central and southwestern Montana is, as has been previously pointed out in this paper, suggestive of the existence of local structural buttresses in central Montana antedating the main period of orogenic activity which formed the eastern ranges of the Cordilleran belt. More definite evidence pointing to the existence of pre-Tertiary uplifts in central Montana is afforded by the sedimentary rocks of the district. Variations in the thickness of the Upper Cretaceous and Lance (Tertiary?) formations point to the inception of such structural features as the Crazy Mountain and Bull Mountain synclines, Porcupine Dome, and the Cat Creek–Devil's Basin horst in early Upper Cretaceous time. The chert pebbles of the Frontier formation of the Crow Indian Reservation and of the Big Elk sandstone member of the Colorado shale of the Musselshell Valley also point to yet more marked uplift within the Bighorn, Pryor, and Big Snowy mountains.

Uplift of the Yellowstone Park Plateau in Lower Cretaceous time is suggestively indicated by the pebbles of the conglomerate of the Cloverly formation of the Bighorn and Pryor mountains, these pebbles being derived in all probability from the black cherts of the Pennsylvanian Tensleep sandstone.

A slight growth of the Bighorn fold in late Jurassic and earliest Cretaceous time is also suggestively indicated by variations in thickness shown by the Sundance and Morrison formations of the Crow Indian Reservation, and a yet earlier pronounced elevation of the Big Snowy and Little Rocky Mountain groups is indicated by the angular unconformity which separates the Jurassic Ellis formation from the Carboniferous in these two uplifts. Evidence of yet earlier growth of the Big Snowies is apparently afforded by a thin coal bed and red shales, developed above the present uplift, in Quadrant rocks, which are characteristically of marine origin, and the same period of elevation may be reflected in the Bighorn Mountains by the slight folding and erosion undergone by the lower Mississippian limestone in pre-Pennsylvanian time.

The numerous large hiatuses in the older Paleozoic rocks of central Montana may conceivably be due to local deformation; it is more probable, however, that they are due to the elevation or depression of the region as a whole relative to sea level rather than to local deformation, except that differential vertical movements along the line of the Lake Basin fault zone in very early times may be indicated by the contrasting Paleozoic sections of the Bighorn and Big Snowy mountains and by the northward termination of the Chugwater red beds just south of the Lake Basin zone.

There is therefore considerable evidence pointing to the existence of local uplifts in central Montana in Mesozoic and later Paleozoic time. The axial orientation of these structural features is a matter of considerably greater uncertainty, but from observations made by the writer in the Crow Indian Reservation it appears probable that the trend of these older folds was almost east and west, bearing perhaps a little to the north of east, affording possible parallels to the older uplifts of the Lost Soldier district described by Fath,[1] to the pre-Cambrian arch which seems to connect the Black Hills or Old Woman anticline with the Sioux quartzite area of southeastern South Dakota, and to the Uinta Mountain fold which seems to have been sheared off from its foundations by subsequent thrust.

[1] A. E. Fath, "The Age of the Domes and Anticlines of the Lost Soldier–Ferris District, Wyoming," *Jour. Geol.*, Vol. XXX (1922), pp. 303–10.

PRESENT STRUCTURAL FEATURES OF CENTRAL MONTANA

As the basis for the quantitative study of the existent structural features of central Montana the writer and Mr. C. E. Dobbin, of the United States Geological Survey, have collaborated in the preparation of a structure contour map (Pl. I) of the region showing the elevation and configuration of the upper surface of the Cat Creek sand, which corresponds closely to the Dakota sandstone of other areas. This map is based largely upon reports by Stone and Calvert,[1] Bowen,[2] Hancock,[3] Reeves,[4] and upon the work of other members of the United States Geological Survey, supplemented by information obtained by the authors of the map, and by well records and local structural maps courteously provided by oil companies and geologists operating in Montana.

Obviously the extension of the contouring to the mountain areas from which the contoured stratum has been eroded involves considerable uncertainties, and the collection of additional data may make some modifications necessary, but the map probably contains no errors sufficiently great to affect seriously the interpretation which may be made as to the origin and interrelationship of the several structural features shown.

[1] R. W. Stone and W. R. Calvert, "Stratigraphic Relations of the Livingston Formation, Montana," *Econ. Geol.*, Vol. V (1910), pp. 551–57, 652–69, 741–64.

R. W. Stone, "Coal Near the Crazy Mountains, Montana," *U. S. Geol. Survey Bull. 341* (1909), pp. 78–91.

W. R. Calvert, "Geology of the Lewistown Coal Field, Montana," *U. S. Geol. Survey Bull. 390* (1909).

[2] C. F. Bowen, "Possibilities of Oil in Porcupine Dome, Rosebud County, Montana," *U. S. Geol. Survey Bull. 621* (1915), pp. 61–70.

C. F. Bowen, "Anticlines in a Part of the Musselshell Valley, Musselshell, Meagher and Sweet Grass Counties, Montana," *U. S. Geol. Survey Bull. 691* (1918), pp. 185–209.

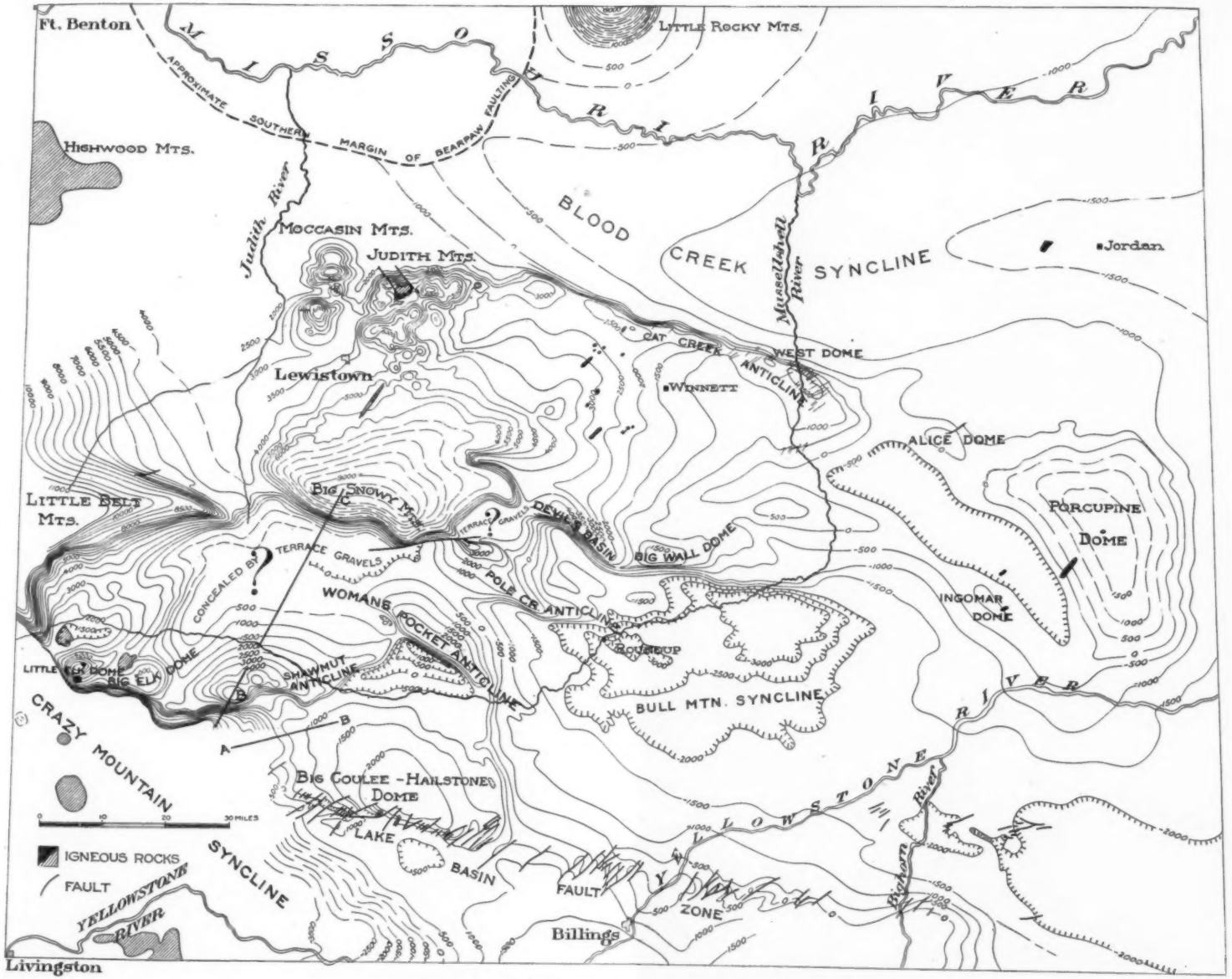
C. F. Bowen, "Coal Discovered in a Reconnaissance Survey between Musselshell and Judith, Montana," *U. S. Geol. Survey Bull. 541* (1914), pp. 329–37.

[3] E. T. Hancock, "Geology and Oil and Gas Prospects of the Lake Basin Field, Montana," *U. S. Geol. Survey Bull. 691* (1919), pp. 101–47.

E. T. Hancock, "Geology and Oil and Gas Prospects of the Huntley Field, Montana," *U. S. Geol. Survey Bull. 711* (1920), pp. 105–48.

[4] Frank Reeves, "Oil Fields of Central Montana," *U. S. Geol. Survey Press Bulletins* (1921).

Frank Reeves, "Geology of Northern Fergus County, Montana," *U. S. Geol. Survey Press Bulletin* (1922).



Structure contour map of central Montana. Contours on Cat Creek (Dakota?) sandstone

From Plate I, the reader will see that central Montana contains a number of strongly developed and asymmetric anticlines which are roughly parallel to the Lake Basin zone of *en echelon* faults which extends for a hundred miles across the southern part of the area.

The dominant structural feature of central Montana is the uplifted block called by Lupton and Lee the Big Snowy anticlinorium,[1] which extends from the Big Snowy and Judith mountains to include the Porcupine dome. The Little Belt Mountains, which seem to be a slightly offset continuation of the same general uplift, are also a pronounced structural feature, as are the Crazy Mountain, Bull Mountain, and Blood Creek synclines. The Little Rocky, Moccasin, and Judith mountains, the domes southeast of the Little Belts, and presumably the Porcupine dome, are laccolithic uplifts, and the Highwood and Crazy mountains are the products of volcanic activity and of dike and plug intrusion. A number of small bodies of igneous rock are scattered here and there over the region and seem to have been intruded without reference to visible structural features except that their orientation is roughly parallel both to the Lake Basin and Cat Creek surface faults, and to the dominant joint system of northeastern Montana. In general there seems to be a genetic relationship between the structure and vulcanism of the area. To a less evident degree the smaller igneous bodies are also probably products of the same forces. Presumably the Big Snowy Mountains and the Porcupine dome have had an origin similar to that already postulated for the Bighorns and Black Hills, and the minor dikes and plugs may have resulted from the injection of magmatic masses formed in the process.

The evidence given by Plate I as interpreted in the light of what is known concerning the geology of central Montana seems to lend quite definite support to the thesis set up by Fath[2] that, in certain areas at least, the structure of the surface rocks has a genetic relationship to faults in the basement complex, and that the move-

[1] C. T. Lupton, and Wallace Lee, "Geology of the Cat Creek Oil Field, Fergus and Garfield Counties, Montana," *Amer. Assoc. Pet. Geol. Bull.* 5, No. 2 (1921), p. 269.

[2] A. E. Fath, "The Origin of the Faults, Anticlines and Buried 'Granite Ridge' of the Northern Part of the Mid-Continent Oil and Gas Field," *U. S. Geol. Survey Prof.* Paper 128-C, 1920.

ment of the crustal blocks bounded by these fundamental faults has played a most important rôle in determining the attitude of the overlying rock strata.

For example, it is believed that the only plausible interpretation for the uplifted area between the Cat Creek and Devil's Basin anticlines is that this area represents a horst in the basement rocks, whose northern edge is marked by the abrupt downward slope of the sedimentary rocks forming the northern limb of the Cat Creek anticline and whose southern edge is similarly marked by the steep southern limb of the Devil's Basin anticline. That these two marginal asymmetric anticlines overlie faults in the deeper rocks is still further indicated by development work in the West Dome at Cat Creek. Drilling in this, the main productive area of the Cat Creek anticline, has indicated that the crest of the arch in the Cat Creek sand certainly does not lie south of the surface crest of the anticline, and that it is probably offset somewhat toward the northern, or steeper limb, which can only mean that the asymmetric anticline in the surface rocks passes into a fault in depth.

If it be granted that the presence of deep-seated faults beneath the Cat Creek and Devil's Basin anticlines may reasonably be considered as established and if the other relationships brought out by Plate I be taken into consideration, it seems rational to believe that the steep southwestern limbs of the Pole Creek and Woman's Pocket anticlines and of the Big Snowy Mountains and Little Elk–Big Elk–Shawmut uplifts are also produced by other basement faults having the same northwest-southeast orientation. The Lake Basin fault zone, which parallels the several features already enumerated, is also probably the product of horizontal movement along a major fracture plane lying beneath the zone, as has been suggested by Chamberlin,[1] and as is strongly indicated by variations in the stratigraphic column on opposite sides of the Lake Basin zone, as has already been pointed out.

The thrust faults of west-central and southwestern Montana are believed to have dissipated the intense compression which other-

[1] R. T. Chamberlin, "A Peculiar Belt of Oblique Faulting," *Jour. Geol.*, Vol. XXVII (1919), pp. 602–13.

wise would have affected the outer part of the earth's shell in central Montana, but it is believed that the deeper part of the crust was subjected to sufficient stresses to produce the differential movement of great blocks of the basement complex, which may or may not have been previously outlined by deep-seated faults. Magma injection also took place either coincident with or subsequent to the crustal block movement. The margins of several of the deep-seated fault blocks, though somewhat masked by the mantle of overlying sedimentary rocks, are yet quite clearly indicated by the visible structural features of the region. The Cat Creek–Devil's Basin horst has been elevated relatively to its surroundings, with a slight tilting toward the east. In contrast, the Crazy Mountain syncline is formed by a block depressed by the transfer of material from a subcrustal to supercrustal position through volcanic eruption. In the main, however, the deforming stress has produced a slight rotation of the blocks without causing a great change in their average elevations. One such rotated block is clearly outlined by the fault zone south of the Hailstone dome, by the line of steep dips east of the dome, and by the triangular depressed area between the Woman's Pocket and Shawmut anticlines. The main uplifted portion of the Big Snowies and the Woman's Pocket anticline seem to be similarly rotated crustal blocks, and the Little Elk and Big Elk domes and Shawmut anticline are also believed to be located along the southern edge of a fourth tilted crustal block whose northern and western margins are indicated by the steep slopes of the Big Snowy and Little Belt mountains. This interpretation of the significance of the structural features developed in the younger stratified rocks of central Montana although independently arrived at, is in all important regards in accord with the theories advanced by Fath[1] to explain the genesis of the domes and anticlines of the Mid-Continent oil field, and the writer's diagram (Fig. 2) which illustrates the downward passage of anticlines into deep-seated faults is also practically identical with one given by Fath. Figure 2 is a theoretical diagram showing the relation supposed to exist

[1] A. E. Fath, "The Origin of the Faults, Anticlines and Buried 'Granite Ridge' of the Northern Part of the Mid-Continent Oil and Gas Field," *U. S. Geol. Survey Prof.* Paper 128 (1921), pp. 75–84.

between basement fault, surface fold, and laccolithic intrusion along the line *B-C* (Pl. I). This diagram is not entirely fanciful, for that part between *A* and *B* is drawn in correct proportion to show the observed thinning of the sedimentary formation against the northwest corner of the Big Coulee–Hailstone uplift (see Pl. I), and the plane of weakness formed by the upward extension of the

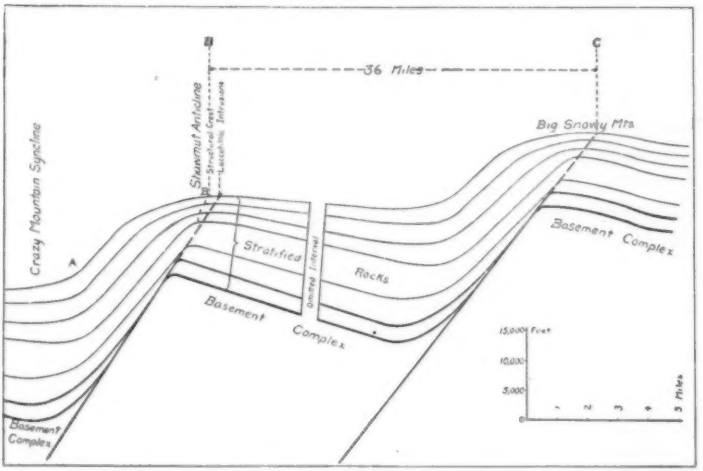


FIG. 2.—Diagram showing assumed relation of surface structural features and subsurface faults in the Musselshell Valley, Montana.

deep fault, which is assumed to be the natural path for rising magmas, intersects the surface at a distance from the steep limb of the anticline corresponding to the position of the Big Elk, Little Elk, and Shawmut domes, which are almost certainly of laccolithic origin.

SUMMARY

From the data presented in the foregoing pages it is concluded that uplifts, probably of east-northeast orientation, were developed in central Montana at various times during the Mesozoic and later Paleozoic, that these uplifts, by acting as resistant buttresses, caused a westward shift of the zone of Eocene thrust faulting believed to be continuous from the Lewis overthrust of northern

Montana at least into Utah. Though the outer crustal shell in central Montana was presumably not subjected to the extreme stress registered by these great overthrusts, it was thrown into waves by elastic bending and plastic yielding, and the deeper-seated rocks were broken into blocks whose differential movements have produced the strongly marked asymmetric anticlines and parallel fault systems developed in the stratified surface rocks of the region. These folds in the surface strata therefore merge downward into underlying faults bounding the deep-seated crustal blocks. The several laccolithic groups of central Montana are believed to have been formed by magmas rising along the fundamental faults and along the upward projection of these planes of crustal weakness.

NATURAL GAS AS A FACTOR IN OIL MIGRATION AND ACCUMULATION IN THE VICINITY OF FAULTS[1]

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INTRODUCTION

In previous contributions[2] the writer has called attention to important relations that faulting bears to the migration and accumulation of oil and gas. It has been pointed out that favorably situated parts of oil- and gas-bearing sands have been enriched by migration and segregation incident to faulting. The escape of water through natural passages, such as fault fissures, has induced widespread hydraulic currents through the beds toward these points of diminished pressure and these water currents, plus buoyancy, have contributed largely toward the migration of oil to favorable rock entrapments in the vicinity of the faults.[3] The propulsive force of expanding gas has been one of the contributing causes for the hydraulic currents.

Paradoxical as it may seem, the escape of gas with entrained oil through fissures has been an important factor in the migration and accumulation of oil in many faulted areas. Compressed gas is the propulsive force by which oil generally moves to producing wells. It is also one of the propulsive forces by which oil has moved with or even ahead of water under conditions of differential pressure brought about by faulting.

[1] Published by permission of the Director of the Bureau of Mines.

[2] R. Van A. Mills, and R. C. Wells, "The Evaporation and Concentration of Waters Associated with Petroleum and Natural Gas," *U. S. Geol. Survey Bull. 693*, 1919.

R. Van A. Mills, Discussion of paper by C. W. Washburne, entitled, "Oil-Field Brines," *Trans. Am. Inst. Min. Met. Eng.* Vol. LXV (1921), pp. 281–90.

[3] See also M. J. Munn, "The Anticlinal and Hydraulic Theories of Oil and Gas Accumulation," *Econ. Geol.*, Vol. IV (1909), pp. 509–29.

John L. Rich, "Moving Underground Water as a Primary Cause of the Migration and Accumulation of Oil and Gas," *Econ. Geol.*, Vol. XVI (1921), pp. 347–71.

The concomitant formation of gas and oil, together with the diffusion of absorbed gas under high pressure throughout the underground water and disseminated oil, are assumed to have preceded the processes herein outlined and have made them possible. Absorbed gas tends to lower the viscosity as well as the specific gravity of the oil, especially where the absorbed gas expands sufficiently to form minute bubbles within the oil. Again under the propulsive force of water currents alone, the oil tends to move less readily than the water, as exemplified by the formation of water cones around producing wells, but where there are considerable proportions of rapidly expanding gas, the oil is propelled ahead of the water. There are of course limiting conditions beyond which the folding and fracturing, or even the erosion of petroliferous strata, have permitted the excessive loss of oil and gas. There are also conditions under which faulting has caused barriers to migration. The statements in this paper are not generalizations. They refer only to conditions that are favorable to the present hypothesis. Where open fissures cutting deeply buried petroliferous beds have formed channels for the migration of oil, gas, and water and have then become sealed sufficiently to retain a part of the oil and gas in the reservoir rocks, the processes herein outlined have evidently functioned.

The purpose of this brief contribution is to present a very small part of the evidence tending to substantiate this hypothesis.

EXPERIMENTAL DATA

During the Bureau of Mines laboratory experiments upon the underground migration of oil and gas through sands, preliminary descriptions of which have been published in *Economic Geology*,[1] there occurred several very instructive accidents yielding unlooked for results. In one of these, the cap sand overlying an improvised anticline was disrupted by gas pressure before the cover plate of the experimental tank was bolted in place, and before the oil and gas, which were intimately mixed with water in the sand, had

[1] "Experimental Studies of Subsurface Relationships in Oil and Gas Fields," *Econ. Geol.*, Vol. XV (1920), pp. 398–421. "Relations of Texture and Bedding to the Movements of Oil and Water through Sands," *Econ. Geol.*, Vol. XVI (1921), pp. 124–41.

segregated. Gas, compressed by the tight tamping of the sands, and accompanied by a little water and oil, escaped violently through the weak spot in the caps and at the top of the anticiline. As the gas moved to the point of escape, it propelled oil into the anticline, the oil accumulating around the point where the gas was escaping.

Other accidents occurred in which the plate glass fronts of the experimental tanks cracked because the water and gas pressures exceeded the strength of the glass. In each of these accidents there was a rush of gas, oil, and water to the cracks or crevices in the glass, and in each case oil accumulated in the sands immediately adjacent to the cracks. The migration and accumulation of oil continued so long as gas moved to, and escaped through, the cracks. Where there were considerable proportions of absorbed gas, the oil was propelled more effectively than the water, and moved to the cracks ahead of the water. These experiments illustrate the migration and accumulation of oil under the influence of faulting either with or without anticlinal structures.

Along this same line, the writer performed the simple experiment of mixing oil with a fermenting liquid (water, apple juice, sugar, and yeast)[1] in a very fine-grained water-wet sand (New Jersey beach sand). The mixture of sand and fluid was tightly packed in ginger ale bottles which were then sealed with caps. At the end of a week these efforts were rewarded by a resounding explosion, followed by a cleaning-up job in the cellar. The next test was run for three instead of seven days. Only a slight gravitational segregation occurred because of the short time period, the very fine texture of the sand, and the high viscosity of the oil which was used. The gas that formed during the fermentation was practically all absorbed under pressure in the oil and water. At the end of three days, a single hole, of pin-point size, was punched through the cap of each bottle. Gas escaped vigorously and the oil throughout the sand started to move upward and to segregate above the water. In about half a minute the accumulation of oil above the water was noticeable, and at the end of two minutes, oil with very little water was jetting from the holes in all of the six bottles used. Each bottle was packed differently to insure valid results but all behaved

[1] The formula is not original.

in practically the same manner. Similar tests were then made in which the bottles were laid on their sides. In each case the oil moved to the points of escape around which it accumulated faster than it was ejected. The principles governing these movements have been previously described[1] but it is well to emphasize the fact that under the conditions of these experiments, the disseminated oil was propelled more effectively than the water by the propulsive force of the expanding gas plus buoyancy. Throughout all of this work the effect of buoyancy operating in conjunction with the other forces was apparent. These experiments are indicative of what would occur if strata containing oil, gas, and water under high pressure were cut by fissures or faults that would permit a part of the fluids to escape.

FIELD DATA

Attention has been called[2] to the fact that in the gently folded and unfaulted Appalachian fields of Ohio and Pennsylvania, the natural segregation of oil above water in some of the productive sands is incomplete. Thus in the Hundred Foot sand of Pennsylvania,[3] and the Keener and Big Injun sands of Southeastern Ohio, a large part of the oil and gas appear to occur intimately mixed with salt water. During the more or less extensive movements of oil, gas, and water toward producing wells, the gas and oil tend to segregate above the water into favorably situated parts of the sands. This has been termed "induced segregation." It is mildly analogous to what happens when hard or lithified strata containing unsegregated gas, oil, and water under pressure are fractured by faulting or fissuring.

Another important analogy between the deep-seated effects induced by oil and gas wells and the effects of faulting is the deposition of practically the same minerals in the wells and in the natural fissures. Calcite, barite, and gypsum, with inclusions of waxy hydrocarbons, accumulate in such quantities in the wells of the

[1] See preceding footnotes, articles in *Economic Geology*.

[2] R. Van A. Mills and R. C. Wells, *U. S. Geol. Survey Bull. 693*, 1919.

[3] M. J. Munn, "Geology of the Oil and Gas Fields in the Sewickley Quadrangle, Pennsylvania," *Pa. Top. and Geol. Survey*, Comm. Sept. 1, 1910, p. 85.

Appalachian and Mid-Continent fields as to cause serious production troubles. Calcite, gypsum, and waxy hydrocarbons occur in the natural fissures, cutting petroliferous strata in many fields. The origin of both types of deposits, those in the wells and those in the rock fissures, can be traced to the escape of water, gas, and oil from petroliferous strata.[1]

The fact that nearly all the productive domes and anticlines in the Rocky Mountain fields are cut by fault fissures furnishes striking evidence that faulting and fissuring have played an important rôle in the migration and accumulation of oil into these entrapments. Probably the best example of this is the petroleum geologists' paradise, at Salt Creek, Wyoming. The huge Salt Creek structure and the somewhat smaller Teapot dome are literally cut to pieces by fault fissures which are evidenced at the surface both by rock displacement and by calcite veins and stringers. At several places in the Salt Creek field the calcite veins and stringers contain ozokerite intermixed with calcite crystals.

Open fissures through which the drill tools dropped several feet have been encountered in drilling wells in the Salt Creek field. Other evidence that there are open fissures in this field is furnished by the occurrence of so-called "shale oil" in commercial quantities in the shales overlying the First Wall Creek sand, by the ejection of calcite crystals along with "shale oil" issuing from wells, and by the escape of oil and gas through these fissures incident to drilling operations. Shale oil and gas in crevices fairly permeate the Steele shale at various depths, sometimes within 4 or 5 feet of the surface. Wegemann[2] has described these features of the field in considerable detail. The so-called "shale oil" wells in the Salt Creek and Teapot fields evidently tap fissures through which the oil has migrated upward from the Wall Creek sands.

Many of the fissures in the Salt Creek field are only partially filled with calcite and much of the calcite filling is porous, with free surfaces of well-defined crystals lining vugs that are empty or filled with ozokerite. The writer has observed this same porous,

[1] See footnote 2, p. 17.

[2] C. H. Wegemann, "The Salt Creek Oil Field, Wyoming," *U. S. Geol. Survey, Bull. 670* (1918), pp. 36–39.

vug-like structure in calcite that was deposited in oil and gas wells near Butler, Pennsylvania.

Evidence that the escape of small proportions of the gas and oil has continued practically to the present time is furnished by the occurrence of numerous seepages in the Salt Creek field. The spotted character of the production, together with phenomenally high initial rates of production of some of the wells tapping fault zones in the Second Wall Creek sand, give further evidences of the relation that faulting bears to underground fluid movements in the Salt Creek field.

Again, the comparatively small productive area in the First Wall Creek sand is probably due, in part at least, to the loss of oil through fissures in the overlying strata. In this same connection there is the possibility that the First Wall Creek sand has received its oil by upward migration through fissures from the Second Wall Creek sand. An example of this type of oil migration and accumulation in Osage County, Oklahoma, was recently described by Paul V. Roundy before the Geological Society of Washington.

These relations of faulting and fissuring to the migration and accumulation of oil and gas are further indicated by the large proportion of productive structures that are faulted in the Mid-Continent, Gulf Coast, and California fields. One of the most interesting examples of oil accumulation under the influence of faulting seems to be the El Dorado, Arkansas, field, which is severely faulted but is practically devoid of any anticlinal structure.[1] The processes herein outlined have probably been largely responsible for the accumulation of oil in that field.

PRIMARY AND SECONDARY GAS ACCUMULATION

For the purpose of this paper the retention and accumulation of a part of the gas that originally accompanied the oil is termed primary gas accumulation, whereas the subsequent migration and accumulation of gas into a faulted entrapment is termed secondary gas accumulation.

[1] "El Dorado Oil Field in Arkansas not on an Anticline." *U. S. Geol. Survey*, press notice 12913, May 15, 1922.

Where the gas originally accompanying the oil and water (primary gas) has escaped through the fissures, the accumulated oil may be practically devoid of gas, as at Soap Creek and Cat Creek, Montana; at Mule Creek, Plunket, Maverick Springs, and other fields in Wyoming; and at Eldorado, Kansas. But where considerable gas under high pressure accompanies oil in faulted and fissured structures it seems probable that this gas is either primary gas retained by the early sealing of the fissures, or that it is secondary gas which formed in, or migrated to the entrapment after the fissures were sealed. It is possible that both phases of gas accumulation are represented in many structures. That there has been an enormous escape of gas incident to the migration and accumulation of oil in most fields is indicated by the high concentration of salts in the waters associated with the oil. This concentration has undoubtedly been brought about through the removal of water vapor in escaping gases.[1]

RETENTION OF OIL

The question is sometimes asked: Why did not all the oil and gas escape from faulted areas before the fissures were sealed? The question might just as well be asked: Why does all the oil not flow from a productive sand through the wells that tap that sand? In both cases, the flow ceases when the propulsive force becomes inadequate to propel the oil to the surface. Let it be remembered that under ordinary conditions of recovery, about 80 per cent of the oil originally contained in a productive sand may, and probably does, remain underground when an oil field is abandoned.[2] As is the case with wells, the complete escape of oil through open fissures has probably failed largely because of dissipated gas pressures, whereas the final retention of the oil is due to the sealing of the fissures before the gas pressures in the vicinity of the faults have again built up through regional adjustments.

[1] See *U. S. Geol. Survey Bull. 693.*

[2] J. O. Lewis, "Methods of Increasing the Recovery from Oil Sands," *U. S. Bureau of Mines, Bull. 148*, 1917.

See also J. O. Lewis, "Our Future Supplies of Petroleum Products," *U. S. Bureau of Mines*, "Reports of Investigations," No. 2174.

SUMMARY

1. Under favorable conditions, especially in firm, consolidated strata, faulting that has yielded open fissures has been an important factor in the migration and accumulation of oil and gas.

2. Differential pressure, caused by the release of pressure through fault fissures, has been largely responsible for the migration of oil and gas to the places of accumulation, enriching the sands immediately around the fissures as well as the fissures themselves.

3. The migration of gas and oil through fissures has been upward either to the surface or from one bed to another. Fissuring has also facilitated the lateral migration of oil and gas through porous beds toward these points of escape. This corresponds with the lateral migration of oil and gas through sands toward producing wells.

4. The propulsive force of expanding gas, more especially the gas absorbed in oil and water under high pressure, has been one of the important factors in the migration of oil through porous strata toward fissures where the pressures were relieved.

5. Oil is propelled more effectively than water by the propulsive force of absorbed gas. Immediately upon the release of pressure, the absorbed gas expands and propels the oil from within. The comparatively high absorption capacity of oil and its tendency to remain entangled with the flowing and expanding gas appears to be largely responsible for this effective propulsion.

6. The migration and accumulation of oil and gas under the influence of differential pressures caused by faulting has been a comparatively rapid process; not the long drawn out process that is generally pictured.

7. The occurrence of faults in the Rocky Mountain and Mid-Continent fields is a valuable criterion in the search for petroleum. In these regions a closed structure that is faulted should generally be given preference to one that is not faulted. Further application of these facts may possibly be made in other fields.

8. Shallow sands have generally undergone more advanced drainage of oil and gas through fault fissures than have the deeper sands. Therefore, in testing a faulted structure, it is imperative to drill to the deeper sands.

DISCUSSION

WALTER ENGLISH asked whether water is ever accompanied by considerable quantities of gas.

LEON J. PEPPERBURG: Approximately 3.5 cc. of methane (CH_4) is soluble in 100 cc. of distilled water at atmospheric pressure. Numerous instances are known where marsh gas is produced from artesian water wells and where the gas is collected from the well-head and used for domestic fuel and lighting purposes. As an illustration I may mention the well on the Freeman Ranch near Fallon, Nevada.

I believe Mr. Mills will be interested in conditions observed near Centralia, Illinois, in 1917. The surface of the Centralia-Sandoval district is covered with glacial drift, and consequently, the known geological structure of the region is based on sub-surface data. Numerous test-holes have been drilled to the No. 6 coal which is found from 500 to 600 feet below the surface. Coal No. 6 is persistent throughout the district, and is a reliable bed for sub-surface work. The coal mines at Sandoval are very dry, in fact, sprinkling is resorted to in the mines to prevent dust explosions, etc. Two horizons produce oil in the Sandoval field: the Stein sand, approximately 840 feet below Coal No. 6, and the Benoist sand, about 950 feet below Coal No. 6. In 1917 the wells in this field averaged about 50 barrels of oil daily.

There were a number of small producing wells in the N.W. $\frac{1}{4}$ of section 32, T. 2 N., R. 1 E., about 4 miles south of the Sandoval field. This locality is known as the Junction City field. The wells averaged 1.5 barrels daily of 34.5 gravity oil. The oil was accompanied by considerable water. There are two producing sands in this district. The Dykstra, about 10 feet thick, found 7 feet below the bottom of Coal No. 6, and the Wilson sand, 15 to 20 feet thick, located about 100 feet below Coal No. 6. Both of these sands are dry (no oil or water) in the Sandoval field. The Wilson sand is the major producing zone at Junction City.

The main shaft of the Marian County Coal Mine is located about $\frac{1}{2}$ mile northwest of the Junction City wells. The underground workings of the mine extend southeast to within less than $\frac{1}{4}$ mile of the Junction City wells. East of the mine shaft the continuity of Coal No. 6 is broken by several faults, in which the displacement ranges from a few inches to 35 feet. The fault zone was observed underground for more than a mile in a north-south direction, and from 20 to 1000 feet in an east-west direction. Within the 1000-feet zone there are three faults east of the shaft. The first has 10 feet downthrow to the east; the second, 30 feet downthrow to the west, and the third, or easterly fault, 5 feet downthrow to the west.

The zones between these major displacements are more or less crushed, and slickensides in the coal are numerous. Water and oil seeps into the mine workings throughout the faulted zone. Pools of water covered with from 1 to 12 inches of oil were observed in the rooms and drifts. Some oil has been produced through the shaft of this mine.

At several places along the major fault the Dykstra sand is exposed. In other words, the bottom of some of the Junction City wells can be examined from the workings of the Marian County Coal Mine. Since Coal No. 6 and the sands 100 feet below this bed are dry at Sandoval, it is my opinion that the oil in the Dykstra and Wilson sands at Junction City migrated upwards along the fault zones in this district, some of which are exposed in the Marian County Mine.

This oil was accompanied by the water. No doubt, a large amount of both oil and water from the deep-seated strata found its way to the surface and escaped. However, a small amount of oil and a large percentage of water found a ready reservoir in the Dykstra and Wilson sands and the oil and water thus trapped is now being produced through the Junction City wells.

Since no evidence of oil was observed in the surface glacial drift, I assume that the major portion of the oil escaped to the surface prior to or during glacial times.

F. H. LAHEE: At the meeting of this Society in Oklahoma City last March, two or three papers were read in which mention was made of certain relations between faults and producing fields. At recent meetings of some other geological societies the same subject has been presented.

Among papers dealing with various aspects of the subject we may cite those by McCoy and Fath—McCoy's treating of the genesis of petroleum, and Fath's discussing the origin of fault systems in Oklahoma.

Today we have already heard several papers, in all of which the bearing of faults on either the origin, or the migration, or the accumulation, of oil has been strongly urged. It seems to me that Mr. Mills's paper is of very great importance in the stress which he has placed upon the significance of faulting. Indeed I am not sure that it does not mark a turning-point in our branch of the science.

Many of the producing pools of today are distinctly related to faults. In most cases the accumulation is anticlinal, but the anticline is broken by one or more faults, and the character of the oil or gas may often be shown to vary in relation to these faults. In some cases the accumulation has occurred in fissure zones or in fault zones without reference to folds. Numerous examples of these conditions might be cited. In addition to those already described today I may mention the El Dorado field in Arkansas; the Monroe gas field, Louisiana, where the gasoline content of the gas rather regularly increases eastward; possibly the new Smackover field in Arkansas; probably the series of new fields in Webb and Zapata counties, Texas; and of course, the salt dome pools.

We used to be called "wrinkle-chasers." It is becoming more and more evident that geological exploratory work must include the search for many conditions beside simple folding. I think that we should be particular hereafter to pay very careful attention to problems of faulting, in both surface and subsurface investigations. This will often mean very intensive study.

In this connection we should remember that the presence of a fault is a factor which may or may not be favorable to the accumulation of petroleum. Faults may serve as channels for migration, or they may be barriers to escape. They may have functioned in one capacity at one period of geological history and in another capacity in a later period. Not only are the finding and mapping of faults difficult, but also the interpretation of their practical or economic importance is bound to be difficult.

In closing these remarks let me say that I do not intend to state it as my opinion that faulting is absolutely essential to petroleum accumulation, but I do believe that fissuring or faulting—that is, distinct fracturing of the strata—is a factor which, more and more will be assigned an important rôle in the origin and accumulation of petroleum.

K. C. HEALD: I feel there is some danger that the necessity for faulting is being so emphasized that if a geologist finds no faults on an anticline he is likely to regard the structure unfavorably. Faults are not needed for vertical migration of fluids across strata. Those of you who have studied metalliferous deposits will remember that many of the richest deposits are found in fissures where no displacement is apparent, and it seems not only conceivable, but probable, that in many instances such fissures have been potent factors in oil migrations.

E. M. PRICE inquired whether the bottle experiment had been tried at other than room temperatures.

MR. MILLS replied that bottles had been sealed and had burst at room temperatures.

THE CURRIE FIELD, NAVARRO COUNTY, TEXAS

FREDERIC H. LAHEE
Dallas, Texas

LOCATION

The Currie Field described below is situated in the southern part of Navarro County, Texas, about 12 miles nearly due north of Mexia. It should not be confused with the Curry Field near Breckenridge in Stephens County, Texas.

HISTORY AND DEVELOPMENT

Several years ago a few shallow gas wells were drilled in the Wortham-Currie district. Except to say that these, like those at Mexia, should have early suggested deeper possibilities, we shall pass over them without further comment.

The first deep well to be brought in was the Meador No. 1, of the Humphreys-Mexia Company. In December, 1921, this well was reported to be producing between 350 and 400 barrels daily, together with a considerable quantity of gas. The second well was the English No. 1, also of the Humphreys-Mexia Company, which was reported, on March 12, to be yielding 4 million cubic feet of gas, and on March 23, 1922, 500 barrels of oil. Since that date some forty odd wells have been brought in, some as gas wells, later going to oil, some as gas and oil wells, and some as oil producers. Some of the later wells had initial yields of several thousand barrels. The gravity of the oil is usually between 40° and 45° Baumé. Most of the wells have yielded water, either soon after being completed, or along with the oil or gas from the beginning. Although there was at first considerable speculation as to the source of this water, it has now been pretty definitely proved to come from immediately below the oil pay. The principal gas pay is above the oil sand, being separated from the latter by several feet of shale or shaly sand.

The usual method of drilling is to use a rotary rig to a point commonly not far from 2,900 feet deep where a hard "shell" often furnishes a good casing seat, to set and cement a string of 6-inch casing at this point, and then to "standardize" and drill in with cable tools.

The Currie Field, at the date of writing, covers an area of less than 1 square mile.

STRATIGRAPHY

Surface exposures at Currie belong to the Midway formation of Eocene age. The strata are principally shales, with some shaly sands. At certain horizons, limy concretions or concretionary layers occur. The Midway lime which is so conspicuous at Mexia, and which outcrops on the Tehuacana range of hills west of Currie, is not exposed in the field. It appears to be absent in its characteristic facies.

Below the Midway group, the drill penetrates, in succession, between 1,700 and 1,900 feet of the Navarro and Taylor formations, about 420 feet of Austin chalk, and about 300 feet of Eagle Ford shales. The Woodbine formation, containing the pay sands of this district, is present immediately beneath the Eagle Ford, at depths somewhat over 2,900 feet. Its entire thickness has probably not been penetrated by any wells in the field.

STRUCTURE

On account of the extensive soil cover, mapping of the surface structure at Currie is difficult. It may be carried out partly by following and contouring the concretionary layers, above referred to, and partly by determining and mapping the dips and strikes of isolated exposures of the various beds in the Midway group. To F. Julius Fohs and his staff of geologists is due the credit of having located the Currie structure.

The remaining portion of this paper will deal with subsurface structure. In subsurface maps and sections of this field, the reader should bear in mind that correlation is liable to a certain amount of error, due to the unreliability of the driller's records and the difficulty of recognizing, in the drilling, the exact boundaries between formations. Consequently, maps made by different geolo-

gists, working with the same logs, are likely to vary considerably. The error in contouring in Figures 1 and 2 accompanying this paper may be as much as two contour intervals.

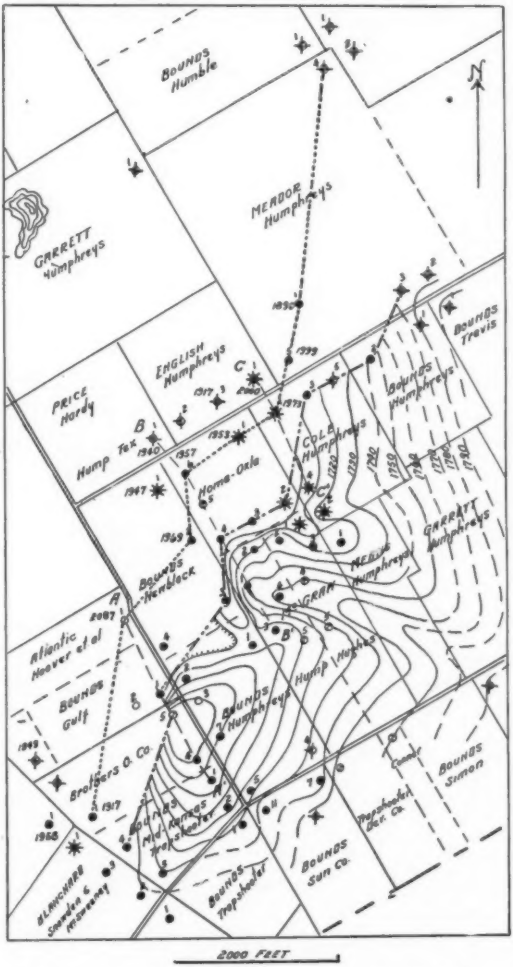

FIG. 1.—Structure contour map of top of Austin chalk

Figure 1 is a contour map of the top of the Austin chalk. Observe that there is very little evidence of reverse dip. The average strike is a little east of north and the average direction of

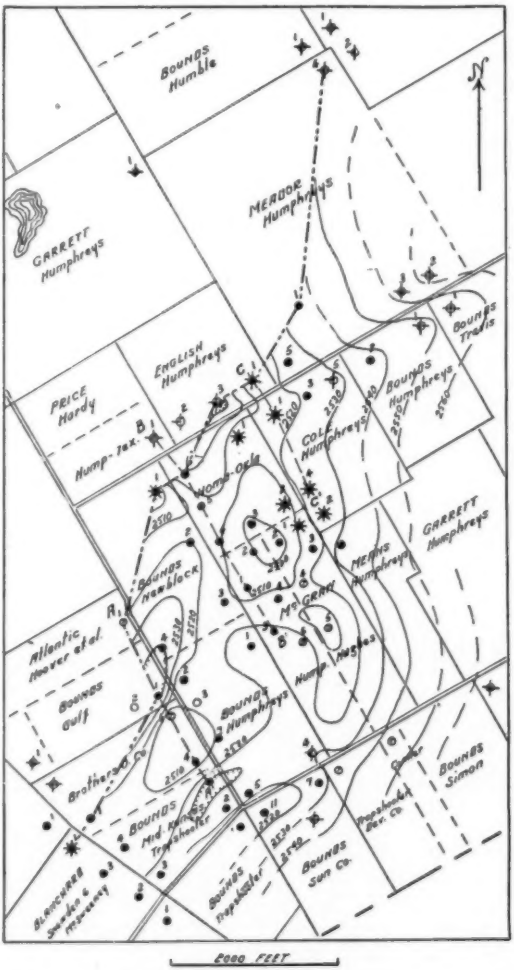

FIG. 2.—Structure contour map of top of Woodbine pay sand

dip is a little south of east, these being essentially the directions of the regional strike and dip. In the contoured part of the map, the elevations of the top of the chalk are between 1,680 and 1,800 feet below sea-level. In the western portion of the field, not here contoured, several wells reached the chalk at depths ranging from 1,890 to 2,000 feet below sea-level. The dash and double dot line connects the westernmost wells in which the chalk was relatively high, whereas the dotted line connects the easternmost wells in which the chalk was low. Within the area between these lines, a fault with a throw of more than 200 feet cuts the top of the Austin chalk.

Figure 2 is a subsurface contour map on the oil pay-sand member of the Woodbine formation, 50 feet, more or less, below the base of the Eagle Ford. The marked difference between the structures shown in Figures 1 and 2 is no doubt to be partly explained by the difficulty of correctly interpreting the well logs. As in Figure 1, the dash and double dot line connects the westernmost wells in which the Woodbine pay sand is relatively high. West of this line, and not very far distant from it, a fault cuts the pay sand. As in the case of the chalk, the downthrow is on the west. Note that this dash and double dot line on this map is considerably west of the position of the corresponding line in Figure 1. This means that the fault has a rather low dip toward the west and is a normal fault.

Figure 3 is a vertical cross-section, drawn to natural scale, through the wells along the line *AA'*. (See Figs. 1, 2, and 8). The break in the Austin chalk lies somewhere between the Atlantic and Hoover School Lot No. 1 and the Gulf Company's R. V. Bounds No. 1, but the break in the Woodbine is west of the first-named well.

Figure 4 is a similar cross-section, drawn along line *BB'*, as indicated on Figures 1, 2, and 8. The fault cuts the chalk between Homa Okla-McGaw No. 4 and Homa Okla-McGaw No. 6, and it cuts the Woodbine between Homa-Okla-McGaw No. 6 and Humphreys' Price No. 1.

Figure 5 is a vertical cross-section along line *CC'* in Figures 1, 2, and 8. Taking *A* as the bottom of the Austin chalk and *B* as

the top of the Woodbine, both in the log of Humphreys-English No. 1, and taking *C* as the top of the chalk in Humphreys-Cole No. 1, and *D* as the top of the chalk in Humphreys-Cole No. 4,

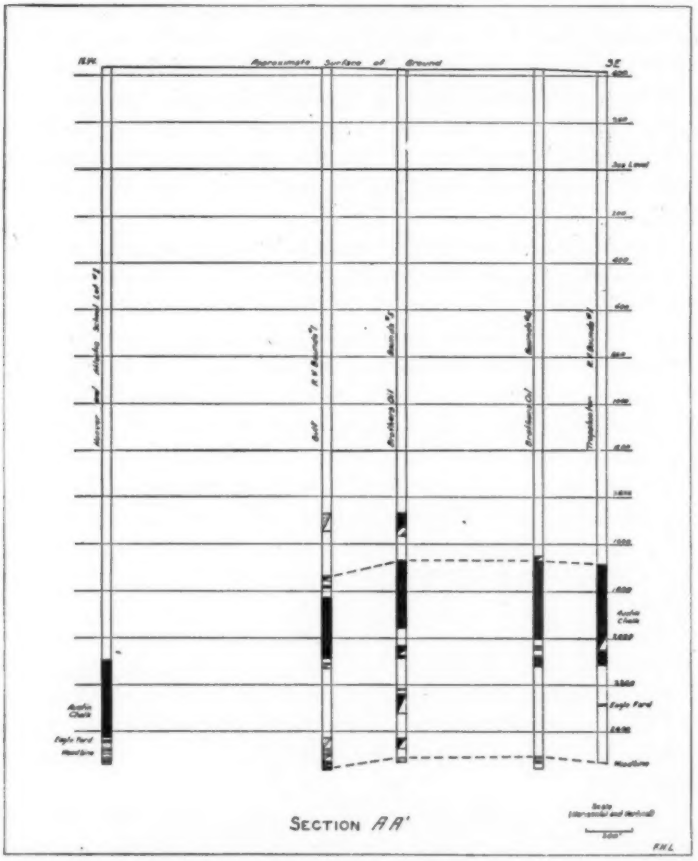

FIG. 3.—Vertical section along line *AA'* shown in Figs. 1 and 2

the fault of which we have been speaking must lie somewhere between *AC* and *BD*. The maximum angle of dip it could have would be 44°, if it had the position *BC*, and its minimum possible dip would be 25°, if it had the position *AD*.

On the basis of a similar interpretation, made previously, Figure 6 was drawn. On the right, a normal fault with a dip[1] of 53° is shown cutting the Austin chalk, the Eagle Ford, and the Woodbine.

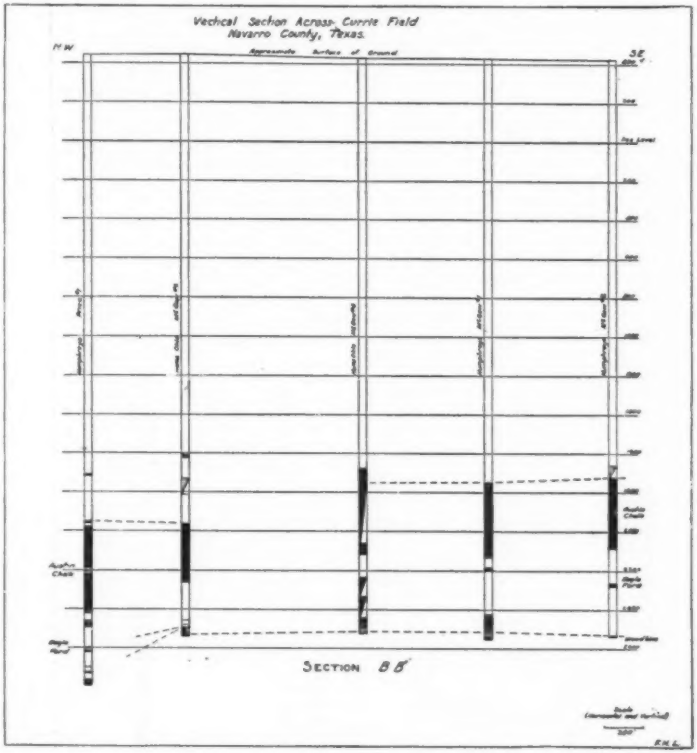

FIG. 4.—Vertical section along line *BB'* shown in Figs. 1 and 2

On the left, a like fault, intersecting the same formations, is drawn with a dip of 24°. These represent, in a purely diagrammatic way, the conditions of maximum and minimum dip of the normal

[1] This diagram was prepared before Fig. 5, and under slightly different conditions. Hence the maximum and minimum angles of the dip of the fault are not quite the same as those shown in Fig. 5. The principle, however, is the same.

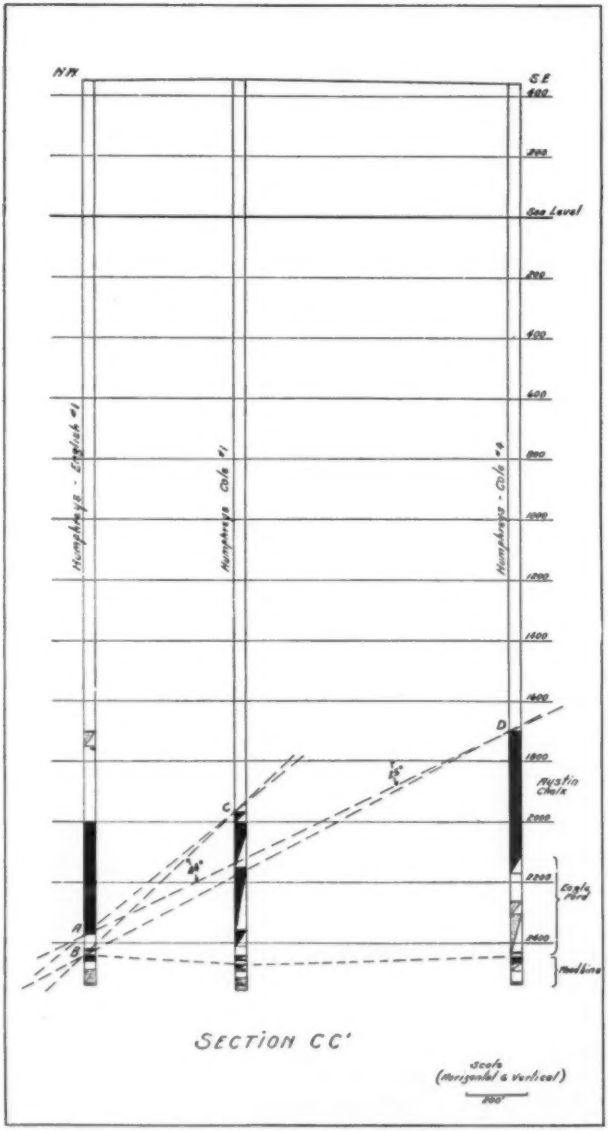

FIG. 5.—Vertical section along line *CC'* shown in Figs. 1 and 2

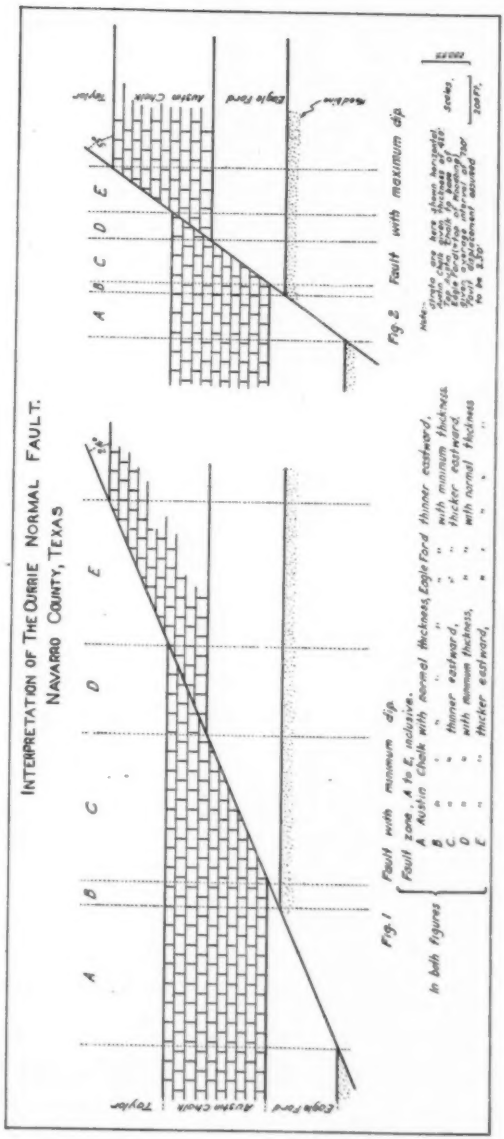
INTERPRETATION OF THE CURRIE NORMAL FAULT.
NAVARRO COUNTY, TEXAS
A
B
C
D
E
Taylor
Austin Chalk
Eagle Ford
Buda Lm.
Fig. 1
Fault with minimum dip.
Fault zone, A to E, inclusive.
A Austin chalk with normal thickness, Eagle Ford thinner eastward,
B " " " " " " with minimum thickness
C " " thinner eastward, " " " thicker eastward
D " " with minimum thickness, " " with normal thickness
E " " thicker eastward, " " " "
In both figures
Fig. 2 Fault with maximum dip
Note:

FIG. 6.—Diagrammatic representation of normal fault

fault. In both sketches, five vertical zones are recognizable. These are lettered from *A* to *E*. In *A* the Austin chalk has its normal

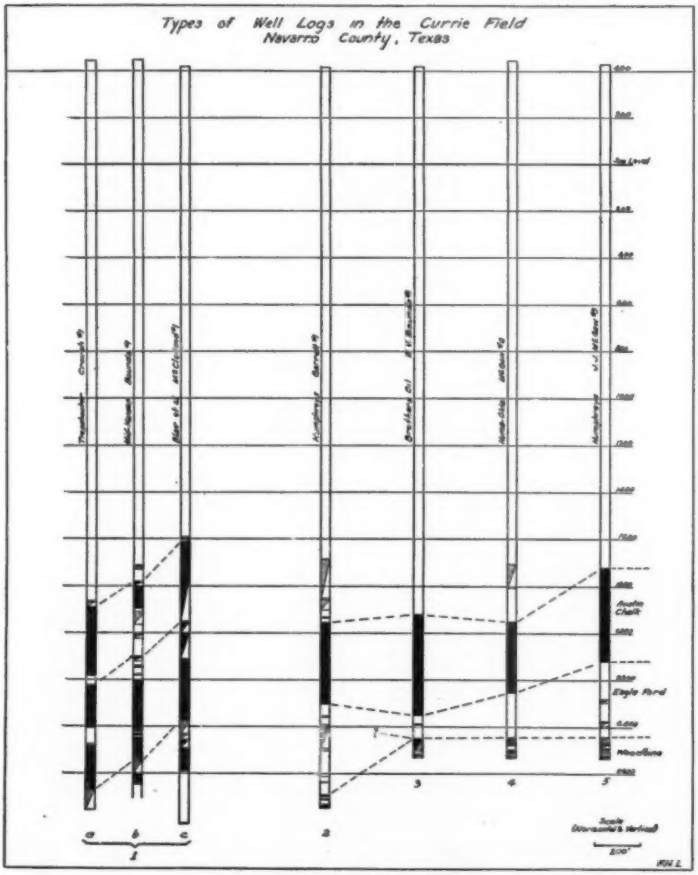

FIG. 7.—Types of well logs in the Currie Field

thickness and the Eagle Ford is thinner eastward.[1] In *B*, the Austin chalk is of normal thickness and the Eagle Ford is nearly cut out.

[1] These sections are oriented to correspond with the actual conditions at Currie.

(See 3, Fig. 7.) In *C*, the chalk thins eastward and the Eagle Ford thickens eastward. Logs of wells in the zone would display a

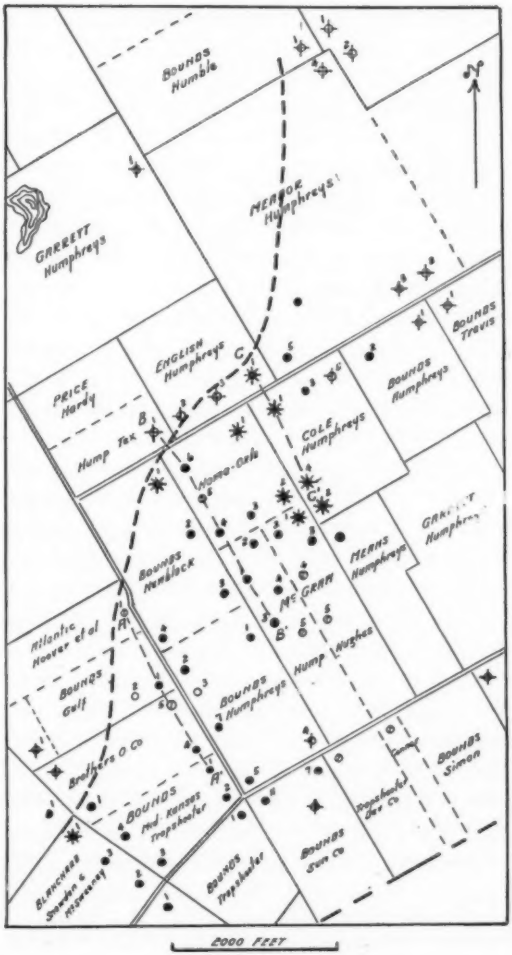

FIG. 8.—Map of the Currie Field, showing the approximate position of the trace of the normal fault where it cuts the top of the Woodbine formation.

reduced thickness of both Austin chalk and Eagle Ford. (See 4, Fig. 7.) In *D*, the chalk has minimum thickness, and the Eagle Ford has its normal thickness. And finally, in *E*, the chalk thickens eastward and the Eagle Ford has normal thickness.

By comparing the logs of wells near the fault with the facts represented in Figure 6, we can find the approximate position of the line where the fault intersects the Woodbine formation. This has been done with the result given in Figure 8. The importance of this study is that it seems to demonstrate rather clearly the probability that the great normal fault at Currie has a markedly sinuous trace on any horizontal plane. The writer believes that this fault and the fault at Richland farther north are one and the same. Indeed, this Currie-Richland fault may very well be the northward extension of the main normal fault of the Mexia Field.

This normal fault at Currie is undoubtedly responsible, in some manner, for the migration and accumulation of the oil and gas, just as the fault at Mexia has controlled the migration and accumulation in that field. Anticlinal folding of the strata is but poorly expressed. It has been only just sufficient to produce reservoir conditions, occurring in association with the fault.

Before closing, attention may be directed again to Figure 7. The three logs at the left (*a*, *b*, and *c*, No. 1) are the records of wells drilled west of the position of the normal fault, and southwest of the pool. They all show an apparent duplication of the chalk. This may be caused by the hardening of a stray chalk in the Taylor formation above the true Austin chalk. If so, the middle dashed line probably represents the top of the Austin chalk. Logs of this character are also commonly given for holes drilled just west of the Mexia Field. It was logs of this nature which first suggested to some geologists the possible existence of reverse faulting west of the Mexia and Currie fields. So far, an entirely satisfactory explanation of these records has not been made.[1]

October, 1922

[1] See discussion following paper on the Mexia Field, by Wallace E. Pratt and F. H. Lahee; this *Bulletin* to follow.

EXPERIMENTS ON BACK PRESSURE ON OIL WELLS[1]

T. E. SWIGART
Petroleum Experiment Station, United States Bureau of Mines,
Bartlesville, Oklahoma

In the production of oil and gas, engineering methods have been applied less than in any other branch of the oil industry. Refineries, gasoline plants, pipe line and other transportation systems and even drilling wells to a great extent, take advantage of engineering skill. The tendency has been to assume that the handling of producing wells was merely a mechanical and routine matter. At present few companies employ engineers to study oil and gas production methods in the light of increasing the general efficiency of recovery, but in view of the advancement in other lines of the petroleum industry by the application of engineering principles, does it not seem likely that the production branch may benefit also by engineering studies?

Engineering applied to the handling of producing wells falls under two general headings: first, the efficient handling of wells from the time of their inception to obtain the greatest possible ultimate production, and second, the rehabilitation of old producing properties that have been handled carelessly in their early lives. To date the engineering work that has been done on oil production problems falls mostly in the second class. The use of vacuum and the application of compressed air have proved successful in some cases in stimulating wells of low gas pressure. These methods are costly to apply and are adapted to small wells in which the gas is almost exhausted, or in which the original gas pressure is negligible. The experiments described in this paper fall under the first heading, as they were made with an idea of learning the probable extent to which the gas production of an oil well can be

[1] This paper, which is an extract of *Bureau of Mines Technical Paper No. 322* now in press, is published by the authority of the Director of the United States Bureau of Mines.

curtailed while gas in the sand is still plentiful and thus saved for doing work during the later period of a well's life. Because of the scope of the experiments, this paper does not include a discussion of back pressure on flowing wells or for purposes other than the cutting down of the gas produced with each barrel of oil.

If it is true that in many fields, natural gas is largely responsible for the migration of oil from the oil sand to a well, then possibly some general relation bearing on the ultimate recovery of oil and gas may be deduced. For instance, it might be found that the ultimate oil production of a well is inversely proportional to the average amount of gas produced with each unit of oil. If true, this would mean that if the number of cubic feet of gas produced with each barrel of oil was reduced by 25 per cent, then the ultimate oil production would be increased by $33\frac{1}{3}$ per cent; or, if the number of cubic feet of gas per barrel of oil was decreased by 50 per cent (one-half of original gas production), the ultimate production would be doubled. Although the foregoing relation cannot be proved even in a general way and probably is not true, there is evidence that the reward for any saving of gas may be so material that no operator can afford to overlook a reasonable opportunity of limiting the gas production of his oil wells to the bare amount necessary to recover each barrel of oil.

Few, if any, records of the actions of oil wells producing under certain back pressures are available. In view of the importance of natural gas in recovering oil and the conflicting reports of the effects of back pressure on both oil and gas production, arrangements were made to actually measure the oil and gas produced by two wells in Osage County, Oklahoma, at different pressures and under certain varying conditions of pressure.

To better establish the effects of pressure and gas control, the entire series of tests were conducted without varying the tubing depths, pumping rate, or other factors, except the pumping time which had to be shortened from time to time as the wells declined, in order to prevent the formation of emulsion (cut oil). The pressure on the casing head was changed now and then, and the oil, gas, and water were measured under the various conditions of pressure. No special effort was made to increase the present oil

production of the wells. It was desired to learn at what pressure the maximum amount of oil could be obtained with a minimum amount of gas even though it cut down the daily oil production. Likewise, it was interesting to learn the relative amounts of oil and gas produced under different pressures, so as to establish what has been defined as the "gas factor of oil production" (cubic feet of gas per barrel of oil).

The experiments were carried on between the dates of September 5, 1921, and March 31, 1922. Although the tests consumed some seven months' time and were as carefully made as field conditions would permit, no claim is made that all the conclusions reached in connection with the wells tested will be applicable to other wells. It is felt, however, that the results may be interesting and important as they bear out certain theoretical principles which have been advanced but heretofore have lacked substantiating evidence.

The wells chosen for test were the Osage Development Company Numbers 1 and 7, Section 35, T. 29 N., R. 11 E., Osage County, Oklahoma. In addition to being two of the best oil producing wells in the pool, both these wells produced comparatively large quantities of gas for that field. Both wells are about 900 feet deep, and both produce from what is believed to be the so-called "Stray" or "Red Sand." Well Number 1 was the discovery well of the Skull Creek Pool. It was favored by having been offset on two sides only and by having a large drainage area on the southwest which was not drawn upon heavily by other wells. Well Number 1 has an 8-inch hole and was given a heavier shot than any other well in the field. Also the 8-inch casing permits of a larger hole at the bottom than in other wells and therefore gives well Number 1 the advantage of greater drainage surface through the oil sand. These factors are responsible, it is believed, for the rate of decline of this well, which is slower than for the average well on the lease. Well Number 1 had an initial production of 125 barrels per day during the first month, but was producing about 29 barrels of oil per day and about 5,700 cubic feet of gas per day against a 21-pound gauge pressure at the time the tests were started. Prior to the time of taking over, this well had produced both against small back pressures and at atmospheric pressure. Seldom had

the pressure on its casing head exceeded 5 pounds, although at times it had reached 10 pounds. The rock pressure of well Number 1 was something over 75 pounds when the tests were started.

Well Number 7 was completed about the same time as its offset Number 6 and only shortly before its other offsets. This well had an initial production of 150 barrels per day and had a slow decline in production during its early life, but later it followed the lease decline rate almost exactly. The offsets to well Number 7 (on all sides except the south) no doubt have caused this well to be more typical of the average well on the lease (from the standpoint of drainage area and oil production) than Number 1. Thus the history of well Number 7, in regard to the number of offsets and their dates of completion, was quite the reverse of Number 1, and to a great extent accounted for the differences in actions of the two wells.

The first closed pressure reading on well Number 7, taken on November 3, 1921, was 49 pounds. The rock pressure of this well was not as high as that of Number 1, but the daily gas production was more than twice as great, being about 13,000 cubic feet per day against a 24-pound gauge pressure. This probably indicates a more porous sand condition at well Number 7 than at well Number 1. Unfortunately, sand samples were not available so that this point could be checked. During the tests, Number 7 was always more sensitive to back pressure than well Number 1. This further indicates a porous sand condition which would increase the interference of offsetting wells, all of which were producing at atmospheric pressure. However, it is believed that the difference in drainage areas is the principal cause of difference in the actions of the two wells.

Well Number 7, at the time the experiments were started, had always produced under back pressures ranging from 15 to 20 pounds and never had produced at atmospheric pressure. By February and March, 1922, the rock pressure of Number 7 was only a few pounds less than the rock pressure on Number 1, and the decline in rock pressure during the seven months of experimenting was not more than 4 or 5 pounds. This is to be expected when the number and distance of the offset of each well are considered, and illustrates to good advantage the effects of offsets on the gas pressure in the reservoir.

In making the tests, the casing heads of both wells were closed and the casing head gas lines run through pressure regulating valves and gas meters. The oil production of each well was gauged separately each day. In addition to numerous odd bits of information, careful records of daily oil production, daily casing head gas production, back pressure, emulsion content and during a part of the time, records of lead line gas produced with the oil from well Number 1, were obtained.

A brief summary of the results of the test is contained in Tables I and II. Both wells were tested first under relatively high pressures (i.e., over 20 pounds per square inch gauge), and the pressure reduced from 5 to 10 pounds about every ten days. The results of these tests are shown under the captions "Stepping Down Pressure" in Tables I and II. The productions of both wells during this period declined, but neither declined as fast as the average decline curve for the lease. The "stepping down" period of the tests consumed about two months.

In order to observe the actions of wells which had been producing at atmosphere, when subjected to gradually increasing back pressures, wells Number 1 and Number 7 were produced at atmosphere for some time and the pressure then built upon them.

The third set of tests made were called "stopcocking tests." They were so designated because of the practice developed in some of the old Pennsylvania fields many years ago, which was known as "stopcocking." Certain wells in these old Pennsylvania fields would produce relatively small quantities of oil but would build up considerable gas pressure when shut in. The practice was to close in these wells and once every few days or each week open the valve on the lead line for a few minutes, during which time they would flow the oil that had collected in the hole. The well then would be closed in again and allowed to "head up." The practice of stopcocking wells was a satisfactory and cheap way of producing oil, excepting that the entire production of oil which a well was capable of making each day may not have been obtained. However, some operators claimed that higher productions were obtained by stopcocking than by usual production methods.

"Stopcocking," as applied to the pumping wells described in this report, consisted of closing in the wells so that they could not

produce casing head gas during the hours they were not pumping and opening them and blowing off the pressure just prior to, and during, pumping. The purpose of these tests was to learn if more oil could be produced with less gas by this method than with a steady back pressure which allowed the wells to gas throughout the entire twenty-four hours at a reduced rate.

TABLE I

SUMMARY OF RESULTS OF BACK PRESSURE TESTS, WELL NUMBER 1

A—Stepping Down Pressure

I	II	III	IV	V	VI	VII
Average Pressure (lbs.)	Average Daily Oil Production (bbls.)	Average* Daily Gas Production (cu. ft.)	Cubic Feet of Gas per Barrel of Oil	Average Production Decline for the Lease (bbls.)	Per Cent Deviation from Average Lease Production	Comparative† Efficiency Based on 21-Pound Pressure (Per cent)
21	28.80	5,708	198	28.8	− 0	100
14.8	29.56	6,849	232	27.7	+ 6.7	85.5
10.9	28.10	7,246	257	26.7	+ 5.2	77.1
5.25	28.90	8,182	283	25.7	+12.4	70.0
0	27.20	5,907	217	24.8	+ 9.7	91.3

B—Stepping Up Pressure

Average Pressure (lbs.)	Average Daily Oil Production (bbls.)	Average* Daily Gas Production (cu. ft.)	Cubic Feet of Gas per Barrel of Oil	Average Production Decline for the Lease (bbls.)	Per Cent Deviation from Average Lease Production	Comparative† Efficiency Based on 50-Pound Pressure (Per cent)
0	23.2	5,341	230	23.2	0	38
20	22.5	4,826	214	22.5	0	41
39.5	20.7	3,982	192	20.6	0	46
50	18.5	1,634	88.4	19.8	−6.6	100

C—Stopcocking Tests

Average Pressure (lbs.)		Average Daily Oil Production (bbls.)	Average* Daily Gas Production (cu. ft)	Cubic Feet of Gas per Barrel of Oil	Average Production Decline for Lease Based on 20.2 Barrels per Day	Per Cent Deviation from Average Lease Production Based on 20.2 Barrels per Day	Comparative† Efficiency Based on First Test (Per cent)	Remarks
Night	Pumping Time							
46.3	11.8	23.4	6,945	297	21.7	+ 7.8	100	closed at night
41	11.8	23.2	8,628	372	21.1	+10.0	80	gassed at night
10	10	22.1	11,146	503	20.5	+ 7.8	59	held at 10 lbs.
0	0	20.2	12,157	602	20.2	0.0	49	held at 0 lbs.

* Includes lead line gas.

† The percentage efficiencies are based on the test at which the well was most efficient in order that they would fall below 100 per cent.

TABLE II

SUMMARY OF RESULTS OF BACK PRESSURE TESTS, WELL NUMBER 7

A—Stepping Down Pressure

I	II	III	IV	V	VI	VII
Average Pressure (lbs.)	Average Daily Oil Production (bbls.)	Average Daily Gas Production (cu. ft.)	Cubic Feet of Gas per Barrel of Oil	Average Production Decline for the Lease (bbls.)	Per Cent Deviation from Average Lease Production	Comparative* Efficiency Based on 24-Pound Pressure (Per cent)
24	16.85	13,072	778	19.4	−13.1	100.0
19.6	18.58	18,730	1,008	18.6	0.0†	77.2
15.3	18.34	20,075	1,130	17.8	− 3.0	68.8
10.2	17.18	19,770	1,150	17.3	− 0.7	67.7
5	16.73	23,360	1,395	16.7	0.0	55.8
0	16.88	25,282	1,496	16.3	+ 3.5	52.1

B—Stepping Up Pressure

Average Pressure (lbs.)	Average Daily Oil Production (bbls.)	Average Daily Gas Production (cu. ft.)	Cubic Feet of Gas per Barrel of Oil	Average Production Decline for the Lease (bbls.)	Per Cent Deviation from Average Lease Production	Comparative* Efficiency Based on 30-Pound Pressure (Per cent)
0	16.5	22,951	1,392	16.5	0	77.8
10	13.53	19,507	1,442	16.3	−17.0	75.0
20	11.80	15,602	1,322	15.9	−25.8	81.8
30	9.75	10,552	1,083	15.5	−37.2	100.0
0	14.84	21,546	1,452	15.2	− 2.4	74.5

C—Stopcocking Tests

Average Pressure (lbs.)		Average Daily Oil Production (bbls.)	Average Daily Gas Production (cu. ft.)	Cubic Feet of Gas per Barrel of Oil	Average Production Decline for the Lease (bbls.)	Per Cent Deviation from Average Lease Production	Comparative* Efficiency Based on Third Stopcocking Test (Per cent)
Night	Pumping Time						
0	0	12.39	10,284	830	12.4	0	74.7
43	0	10.75	7,375	686	11.9	−9.6	90.3
20	0	11.78	7,301	619	11.4	+3.3	100.0
0	0	12.00	9,480	790	11.0	+9.1	78.4‡

* The percentage efficiencies are based on the test at which the well was most efficient in order that they would fall below 100 per cent.

† Adopted as origin because 24-pound pressure materially decreased production.

‡ Benefits from pressure which had built up in sand.

The importance of setting down records and preparing charts, tables, etc., to permit of ready comparison and weighing of the data obtained, is paramount when conducting tests of this nature. It was found that in so far as the oil production was concerned, charts

bearing the actual production curves of the wells upon which were superimposed segments of the production decline curve of the "average well on the lease" were by far the most illuminating. Likewise in preparing Tables I and II, use was made of the decline curve of the average well on the lease.

The gas productions per barrel of oil or "gas factors of oil production" Columns IV, are used in computing Columns VII of Tables I and II. The method of handling the wells, which resulted in the smallest gas production per barrel of oil, was considered the most efficient from a production standpoint. Comparative efficiencies of other tests of the same set are computed on that basis. Some of the tests showed decreased oil productions but at the same time higher efficiencies because less gas was produced per barrel of oil. Thus, while the daily oil productions seemingly are of utmost importance in gauging the effectiveness of various methods of handling the well, the "Gas Factors of Oil Production," because they take into account both oil and gas production, are the true measures of efficiency.

SUMMARY

The following summary has been drawn partly on the basis of the results obtained during the field experiments on back pressure and partly from data and opinions resulting from a study of oil well production methods in various fields of the United States which is now being attempted. Because the experiments have been confined to two wells in one field and other data are incomplete, many of the conclusions must be regarded as suggestive rather than as definite. A number of the following conclusions will not be applicable to wells under different conditions, but it is believed that many of the conclusions may be common to wells in other areas. The wells referred to are wells that produce by gas pressure and not by water pressure.

1. A differential in pressure between the well and outlying portions of a natural underground oil reservoir is essential for the movement of oil toward the hole. As the rock pressure in the oil-bearing formations declines, the pressure at the well must be lowered "ahead" of it to insure a flow of oil and gas toward the well. To maintain this differential after the rock pressure has

declined to a low point, vacuum, many times, is put on the wells. The magnitude of this differential will depend upon a large number of variable factors, many of which cannot be determined. Therefore, actual field tests on individual wells, or part of the wells on a property with fairly uniform conditions, must be made before the most efficient differential can be determined.

2. As underground conditions, as regards pressures and arrangements of fluids, in oil fields are constantly changing, one set of tests to determine the best differential pressure cannot be accepted for the basis of operations over a long period of time. Tests must become a part of the operating routine. The operator, after making a few tests, will be able to decide upon the frequency with which future tests should be made. It is the writer's opinion that once an operator becomes thoroughly conversant with his wells, the need for tests will not arise often enough to be burdensome.

3. Both absorbed and free gas, if free gas is present, assist oil in migrating from outlying portions of the reservoir to the well. The greater the rock pressure and consequently the greater the quantity of natural gas in the reservoir, the greater will be the ultimate recovery of oil from a well. Experience has shown that relatively small amounts of oil are recovered by natural methods, from a well after its gas pressure has declined to a very low level.

4. If the preceding conclusions hold, it may be said that methods, which will permit the extraction of oil from natural underground reservoirs with a minimum amount of gas per unit of oil, are those which will insure the greatest ultimate recovery of oil. Operating methods that permit or encourage the escape of more gas than the minimum amount required to bring each unit of oil into the hole will lessen the amount of oil which ultimately may be recovered.

5. By holding back pressures on a pumping well, the daily gas production may be reduced appreciably. In general, the greater the back pressure the less the daily gas production.

6. Fairly large back pressures can be held on many pumping wells, without cutting down their oil productions, and back pressures approaching closely the potential rock pressure of the reservoir can be held on some wells at a sacrifice of only small percentages of their present daily oil productions.

7. Back pressures which are most effective in increasing the efficiency in oil recovery (by cutting down the number of cubic feet of gas per barrel of oil) are those pressures which do have a noticeable effect on the present daily oil production. However, the higher the back pressure, the greater seems to be the rate of increase in efficiency of production (i.e., the greater become the reductions in cubic feet of gas per barrel of oil with every equal increase in pressure).

8. By closing in well Number 1 which was in the nature of an isolated well, and permitting only that gas which came through the lead line to escape, it was found that the daily oil production was decreased 7 per cent, and the number of cubic feet of gas per barrel of oil was decreased by two-thirds. Doubtless, such a small decrease in present daily oil production would be compensated for by the increase in ultimate recovery, many times over.

9. A well which was offset on three sides at the usual distances by wells producing at atmospheric pressure (well Number 7), and which drained a fairly porous sand, was sensitive to back pressure. A back pressure of 24 pounds when the potential rock pressure was over 50 pounds caused a loss of 13 per cent in present daily production, while a back pressure of 30 pounds reduced the daily oil production by 37 per cent. High back pressures are not practical for wells that are closely offset by wells producing at atmospheric pressures.

10. Stopcocking raised the present oil production of well Number 1 from 8 to 10 per cent over the normal oil production at atmospheric pressure, and 18.2 per cent over the oil production of the well at a 50-pound back pressure.

The loss in efficiency by stopcocking, due to the production of gas in excess of the amount produced per barrel of oil at 50 pounds' pressure, amounted to more than 23 per cent. Therefore, although the present daily oil production was greatly increased by stopcocking, the amount of gas used per barrel of oil was three and one-third times that used per barrel of oil at 50 pounds' pressure, and such practice no doubt would cut down appreciably the total ultimate production that could be obtained if the back pressure on the well was kept near the potential rock pressure.

11. Stopcocking injured the production of well Number 7 (offset on three sides) when the well was closed in each night. Prior to stopcocking the well had been producing at atmospheric pressure for fifty days. Later stopcocking increased the production of the well 3 per cent when only 20 pounds' rock pressure was allowed to build up each night. It is believed that while gas pressure was being established in the sand which had been under low pressure during the run at atmospheric pressure, the daily oil production was reduced and as the new arrangements of fluids took place, the well regained its normal production.

12. Stopcocking probably will increase the oil production of most wells. If the well is closely offset by wells at low pressure, the overnight pressures must not become too high else the oil production may suffer at the gain of the offset wells. Stopcocking may or may not be efficient from the standpoint of gas production with the oil. In general, stopcocking will be more successful after the rock pressure has built up in the reservoir near the well. If stopcocking is started with the pressure near the well at 0 pounds' gauge, the first month of handling will probably cause a decrease in oil production, but continued stopcocking should increase the oil production.

13. While the gas pressure is still good, the producing of wells with open casing heads will result in inefficiency. For instance, well Number 7 averaged 21,546 cubic feet of gas per day during the period from December 18 to 30, 1921, with the casing head open (atmospheric pressure.) Excepting for about thirty days at odd times, it had never produced at atmosphere during its life of approximately one and one-third years. After producing at atmosphere from December 18 to Feburary 20, its daily gas production dropped to approximately 10,300 cubic feet of gas per day, or 50 per cent, indicating that at atmospheric pressure the well had blown off a considerable part of its "head."

14. Back pressure held on wells that have been producing at lower or atmospheric pressures will reduce the oil production at least temporarily because of the decreased rate of flow of gas and oil toward the hole during the time that the pressure is building up in the sand. After a relatively high pressure has been built up in

the sand between the well and more remote portions of the reservoir where the maximum rock pressure of the particular locality exists, comparatively high back pressures may be held without seriously cutting down the oil production. Enough time to permit a re-establishment of high pressure near the well must be allowed before the true effects of the pressure can be gained.

15. Wells produce casing-head gas at a faster rate when they are pumping and when the fluid is pumped down than when they are shut down and there is a column of fluid in the hole. The fluid column which builds up when wells are shut down usually is effective in materially reducing the rate of flow of casing-head gas.

16. The wells tested did not cut their oil because of back pressure. They did cut their oil, however, because of leaky cups and valves or when pumped after they had begun to pump off.

17. The holding of back pressures should increase the flowing life of wells. The employment of the back pressure method of handling wells no doubt will bring into prominence flowing devices by which relatively small wells will flow their production with their own gas pressure. Increasing the flowing life of a well is important not only from the standpoint of increased recovery but from reduced operating expense.

In this paper data have been presented to show the effects of holding back pressures on two wells. These data for the most part, bear out theoretical conclusions, many of which have been advanced previously by Bureau of Mines engineers. Practically all oil men from the oldest experienced field man to the petroleum engineer agree that "when the gas is gone," the average oil well may be considered as practically exhausted. Experienced oil men agree that if gas could be conserved and therefore the rock pressure in the oil sand sustained above the usual level, oil wells would decline more slowly in daily production. This, of course, would result in a greater total ultimate production of oil from each well.

Holding back pressures on pumping wells may afford a method of cutting down the gas production per barrel of oil. However, the back pressure method of handling wells is not recommended for indiscriminate use. In many localities it will be impractical.

It is felt, however, that the tests described in this report indicate the possibilities of holding pressure and increasing the efficiency of production and, possibly, will serve as a basis for future work in the scientific production of oil. The chances for increasing the ultimate oil production apparently are of such nature as to warrant consideration of this method or other improved methods which may be developed.

Full acknowledgement is made to the Osage Development Company, owner of the lease, and in particular, to Mr. Paul F. Dahlgren, of that company, who turned over to the writers the entire handling of the two wells tested. The Indian Territory Illuminating Oil Company kindly furnished the gas meters used and kept them in repair.

Mr. Charles R. Bopp, of the Bureau of Mines, rendered invaluable service in connection with these tests and is a coauthor of the complete *Bureau of Mines Report*, also entitled, *Experiments on Back Pressure on Oil Wells*. Other members of the bureau assisted in various ways.

Bureau of Mines Technical Paper No. 322, now in course of publication, contains detailed descriptions of the field, the wells tested, mechanical methods employed in conducting the tests, together with complete information concerning the variations in oil and gas production and discussions of fluid levels, back pressures, and other topics which could not be incorporated in this paper and will be available within a few months to any interested in work of this nature.

DISCUSSION

E. L. ESTABROOK: I rise to defend the "independent operator." The Midwest Refining Company is now conducting an elaborate series of experiments in the Salt Creek Field, Wyoming, to determine the method of production which will be most economical in the use of gas. The problem there deals with flowing wells instead of pumping wells as tested by Mr. Swigart, so there is a saving to be made not only by conserving the gas for its expulsive effect in driving the oil out of the sand and into the well, but also for its lifting energy in raising the oil to the surface.

SOME SUGGESTIONS IN REGARD TO PENNSYLVANIAN PALEOGEOGRAPHY IN THE HENRYETTA DISTRICT, OKLAHOMA

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Among the features of the Henryetta district that are well known to the geologists who have worked in the area, are a few that seem not to have been described. Some of them, if their significance were thoroughly understood, might throw considerable light upon the history of Oklahoma during Pennsylvanian time. In the hope of calling forth other facts and ideas about this district, it is proposed to describe two of these features, and to suggest some possible explanations.

For much valuable criticism of the ideas contained in this paper, the author is indebted to several geologists who have worked in the area. He is under special obligation to Professor Eliot Blackwelder.

The features of the Henryetta district, to which particular attention is here directed, are the character and relations, and possible origin, of a thick sand-body, known as the "Booch," the "Second Salt Sand," and by various other names; and the remarkable change in character of certain formations north and south of an east-west line which runs approximately through Henryetta.

The belt of thick Booch sand is shown on some published sections, such as that of Aurin[1] and others, and is mentioned in various discussions of the Henryetta district, such as that of Bloesch.[2] As shown on the map, Figure 1, its thick portion, to which attention is here limited, is at least 30 miles long, and from 2 or 3 to 5

[1] Aurin, Clark, and Trager, "Notes on the Subsurface Pre-Pennsylvanian Stratigraphy of the Northern Mid-Continent Oil Fields," *Amer. Assoc. Pet. Geol. Bull.* sec. from Okmulgee to Muskogee, Vol. V, opposite p. 144.

[2] "Unconformities in Oklahoma and Their Importance in Petroleum Geology," *ibid.*, Vol. III, p. 283.

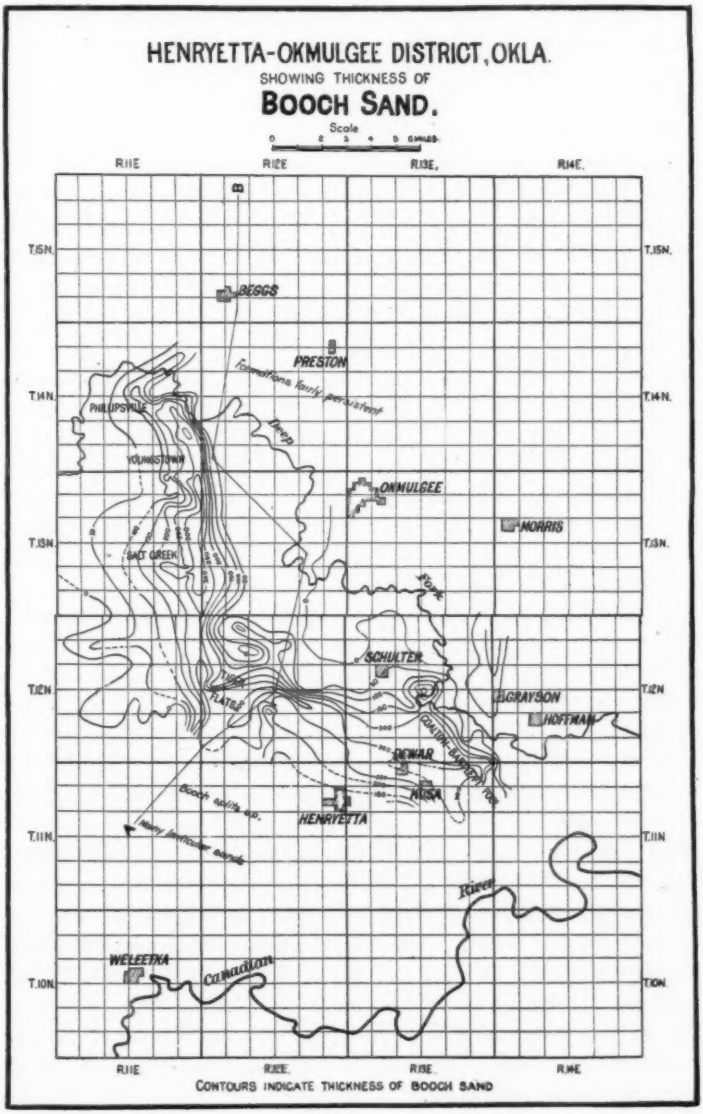

HENRYETTA-OKMULGEE DISTRICT, OKLA.
SHOWING THICKNESS OF
BOOCH SAND.
Scale
R.11E.
R.12E.
R.13E.
R.14E.
T.15N.
T.14N.
T.13N.
T.12N.
T.11N.
T.10N.
BEGGS
PRESTON
PHILLIPSVILLE
YOUNGSTOWN
OKMULGEE
MORRIS
SALT CREEK
SCHULTER
GRAYSON
HOFFMAN
DEWAR
HENRYETTA
WELEETKA
Canadian
River
CONTOURS INDICATE THICKNESS OF BOOCH SAND

FIG. 1

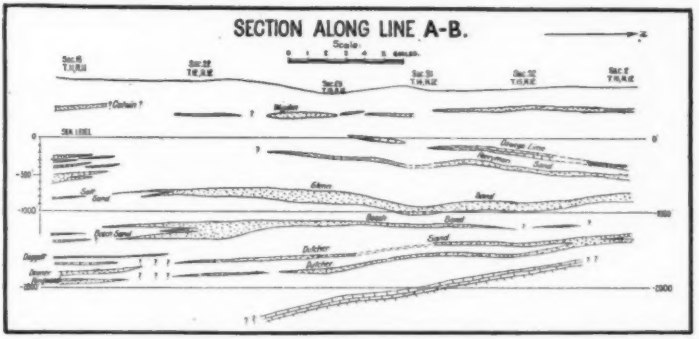
or 6 miles wide. Its limits to the north and south are not definitely shown on the map, which was rather hurriedly made about two years ago, and has not been kept up to date as new information became available. It appears to extend several miles farther south than the map indicates, however, and perhaps indefinitely far toward the southeast, where few records are available.

So far as the part shown on the map is concerned, the Booch shows some similarity to various channel sands and bar sands that have been described. It has, however, several peculiar features. One is its shape in ground plan, which may of course be partly due to inaccuracies of the logs. Another peculiar feature is its shape in cross-section. If one may judge from two cross-sections carefully made, one near each end of the part mapped, the sand-body appears to be practically flat on top, and to be roughly convex downward. The shape is made very irregular, however, by the way the beds of sand composing the lens interfinger with the adjacent shales. Still another peculiar feature of the Booch sand is its change in character, along with all the associated formations, when traced south across the east-west line through Henryetta, which has already been mentioned.

In regard to the origin of such a sand-body as the Booch, exact data are perhaps too few to make speculation profitable. Considering only the shape in cross-section, one would probably be inclined to look with favor upon the river channel hypothesis. Some other considerations, to be mentioned later, tend on the other hand to make the sand appear to be some sort of spit or barrier beach.

The most remarkable fact of all about the Booch sand, however, is its apparent relation to a line of very productive oil fields. Beginning at the north end of the portion shown on the map, the Booch underlies the Beggs Field, Phillipsville, Salt Creek, Youngstown, the Stebbins Pool, most of the good pools in Tiger Flats, and the Coalton-Bartlett Field. Compared with any other area of similar dimensions in the district, this one underlain by the thick Booch sand mass appears to be unusually productive. The causes of this curious association are not made any more evident by the statement that only a little of the oil in the pools named comes from the Booch sand itself.

When all possible aspects of the problem are considered, the only fairly certain conclusion that emerges is that the relation, if it is more than an interesting coincidence, must be due to some control exercised by the thick Booch sand-body, upon the structural relations of the associated shales and sandstones. It appears that the mere presence of such a body might by differential settling cause a slight bend in the overlying beds, and that this bend might then influence the manner of yielding of the whole series if the beds were subjected at a later time to lateral pressure. It may even


SECTION ALONG LINE A-B.
Scale:
Sec. 18 T.11N.R.11E
Sec. 17 T.11N.R.12E
Sec. 16 T.11N.R.13E
Sec. 15 T.11N.R.14E
Sec. 14 T.11N.R.15E
?Calvin?
Wapbanucka
SEA LEVEL
0
-500
-1000
-1500
Glenn
Booch
Dutcher
Dutcher
Booch Sand
Glenn Sand
Booch Sand
Dutcher Sand
Dutcher Sand
Wapbanucka Sand
Wapbanucka Sand
Calvin Sand
Calvin Sand
Glenn Sand
Booch Sand
Dutcher Sand
Wapbanucka

The section seems to show clearly enough that the pre-Thurman, post-Dutcher formations, several of which are well known in the eastern Oklahoma oil fields, and some of which can be traced much of the way from the Kansas-Oklahoma line to Henryetta, become rapidly unrecognizable south of Henryetta. It suggests one reason why so few of the sections that have been published to show conditions in eastern Oklahoma have extended south of Henryetta. It suggests further a possible reason for a deficiency in the interesting study of the Deaner Field, made by Bureau of Mines investigators. In discussing subsurface stratigraphy, these men[1] mention the sands that should occur above the Dutcher, but make no attempt to identify them on the logs from the Deaner Field. A little study of the plotted well logs published with their paper suggests an entirely adequate reason. There is much more variation in the logs of adjacent wells in the Deaner Field than there is for example between a typical log from Tiger Flats and one from the Bristow area, 30 miles northwest.

In this connection it is interesting to compare Taff's[2] description of the pre-Thurman rocks of the Coalgate region with the corresponding beds near Henryetta. According to the Coalgate Folio, the pre-Thurman rocks are about 8,000 feet thick and are divisible into five formations by the presence in the series of two somewhat persistent sandy horizons. If these sandstones, the Hartshorne and the Savanna, were absent, the whole series would have to be grouped as one formation, a great thickness of shales, coal, sandy shales, and sandstones, none of them laterally persistent. A number of detailed sections from such a series of rocks would be comparable to the logs from the Deaner Field. In the present state of knowledge, then, the suggestion may be entertained that all the variable rocks above the Dutcher, in the Deaner Field, may be similarly variable farther south, and that there was a markedly different set of conditions of deposition north and south of Henryetta.

To infer the exact conditions of deposition of any series of rocks is likely to be a difficult matter. The controversies that still rage

[1] M. J. Kirwan and F. X. Schwarzenbek, *Petroleum Engineering in the Deaner Field*, pp. 3-4 (U.S. Bureau of Mines and Bartlesville Chamber of Commerce).

[2] J. A. Taff, *U. S. Geol. Survey Atlas*, Coalgate folio (No. 74) (1901).

about the origin of many well-known and long-studied formations are sufficient proof of this fact. When most of the available data about the rocks must be obtained from well records, the task is certain to be even more difficult than usual. The meagerness and uncertainty of the data make the number of possibilities very large, and the difficulty of deciding among them insuperable. Instead of discussing all the possibilities, therefore, it may be sufficient in the present instance to state the evidence for and against one hypothesis that seems to account for the facts somewhat better than any of the others that have been considered.

The favored hypothesis may be introduced by the quotation of a description of a formation that has some points of similarity with the rocks under consideration here. Grabau[1] writes:

> The numerous (20 or more) well borings made into the confluent deltas of the Po, Etch, and Brenta, in the region about Venice, have revealed the fact that the structure of the delta is an extremely heterogeneous one. While the beds are, in general, horizontal, with only minor undulations, the succession is scarcely the same in any two of the bore holes. This proves that the beds of the delta form a succession of lenticular masses, of very limited extent. Only two sandy layers, carrying water, have proved in any way constant; all others quickly wedge out laterally.[1]

He states further that some beds are lignitic and that there are occasional layers containing marine fossils. Most of the beds are shown to be non-marine; that is, they belong to the subaerial topset beds of the delta.

These Italian delta beds have rather surprising similarities to the Pennsylvanian beds of the Deaner Field. They suggest the possibility that during much of Pennsylvanian time the region south and east of Henryetta may have been a broad delta, or series of deltas; a subsiding coastal plain over which aggrading rivers wandered. The shore zone doubtless shifted widely, so that marine beds are interbedded with the dominantly fluviatile deposits. North of Henryetta, on the other hand, the beds are, on this hypothesis, dominantly marine. They are probably in large part the submarine topset beds of the deltas which were building northward into the epicontinental sea of that area.

[1] A. W. Grabau *Principles of Stratigraphy*, p. 613.

As a partial test of the delta hypothesis, it may be interesting to see how much room it leaves for sand-bodies of the type of the Booch. Study of such a modern example as the delta of the Rhine and associated streams suggests that the Booch sand might be equivalent to the line of sand bars that there separates the non-marine delta beds of Holland from the marine portion of the delta which is accumulating in the North Sea. That such conditions may have existed locally during the Pennsylvanian period is suggested by David White.[1] In discussing the origin of the Appalachian Coal Measures, he says:

> At other times, great areas, probably embracing most of the depositional region, were either above water or so near the surface that sand barriers or bars, possibly in series, and probably more or less irregular in plan, developed far out toward the edge of the submerged shelf, constituting series of lagoonal or landlocked shallows of enormous aggregate extent. Where not too deep or subject to vigorous incursions of the sea these were occupied by the coal-forming vegetation.

This paleogeographic deduction, applied by its author to the Appalachean trough, may be found to apply equally well to southeastern Oklahoma. At the same time, it may be well to state again that the Booch sand seems to have only a part of the characteristics that would be expected of an ancient sand bar. Its origin might turn out to be quite different without necessarily weakening the delta hypothesis as applied to the associated formations.

It seems entirely possible, also, that the delta hypothesis may be just the factor needed to complete the explanation of the distribution of oil in a part of eastern Oklahoma. The stage of metamorphism as shown by the coals is undoubtedly a factor, but does not appear to be the only factor. In suggesting that the additional factor may be sedimentational or diagenetic, McCoy[2] has expressed what is probably the opinion of the majority of geologists who have worked in the district. Under the delta hypothesis, as sketched above, the lack of oil south of Henryetta may be cor-

[1] White and Thiessen, "Origin of Coal," *U. S. Bureau of Mines Bull. 38*, p. 54.

[2] A. W. McCoy "Mid-Continent Paleogeography," *Amer. Assoc. Pet. Geol. Bull.*, Vol. V (1921) pp. 570–71.

related with the dominantly non-marine origin of the rocks. The oil north of Henryetta is in the supposedly marine beds, which accumulated offshore to the north. Since subaerial delta beds are usually considered to have at most gas and coal, but rarely any oil, the facts of distribution seem to be in accord with the theory proposed.

The Dutcher sands, it may be well to note specifically, are not included in this discussion. If the Dutcher is to be correlated with the Morrow and Wapanucka, as has been suggested,[1] its conditions of deposition would naturally be expected to be very different from those of the later formations. Even if this correlation is at fault, however, the facts in regard to the distribution and character of the Dutcher forbid that it should be included with the overlying formations in a discussion of origin.

In conclusion, so far as the facts that are available indicate, the delta hypothesis accounts with a fair degree of success for many of the important geologic features of the Henryetta district. Beds similar in many respects to those found in the district are accumulating in association with deltas at the present time. Similar deltas have been invoked to account for somewhat similar conditions in other parts of the United States. The peculiar Booch sand promises, albeit in a somewhat doubtful manner, to fit nicely into the scheme of things which a Pennsylvanian delta would require us to assume in the Henryetta district. And finally, the somewhat puzzling distribution of oil and gas in southeastern Oklahoma seems to gain from the delta hypothesis the part of its explanation which earlier discussions have not given.

DISCUSSION

ED. BLOESCH: The scarcity of production in the Booch sand in the area of its great thickness may be explained through lack of important structure. The Salt Sand of the Okmulgee district is also of great thickness and produces in only a few places.

The difficulties of correlating the Okmulgee territory with the Coalgate district are partly due to increase in thickness, which can be observed at the surface south of Muskogee. The bottom sandstone of the Boggy, which is probably the Salt Sand, splits east of Checotah, and the intervening shale increases to a thickness of several hundred feet in less than 10 miles.

[1] Aurin, Clark, and Trager, *op. cit.*

OIL ACCUMULATION IN RELATION TO PERIODS OF FOLDING

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Much stress has been laid upon the importance of geological structure as a necessary cor dition affecting oil and gas accumulation. All deposits of these substances, when studied in detail, are seen to depend on a number of factors, of which the structure is one. In the various provinces where oil and gas have been found, rocks of different ages, ranging from Cambrian to Pleistocene, inclusive, are involved, but as a rule the age of the oil- or gas-bearing rocks in any one locality does not extend over many periods, and the accumulation appears to be related to periods of folding in a more or less direct manner. Little attention seems to have been paid to the *time* when the structures were formed, and the effect that it may have on the probability of finding oil or gas in untested areas.

It is self-evident that there may be a great difference between the age of a formation and the time when a structure favorable for oil or gas accumulation is impressed upon it, and, accordingly, it seems important to inquire just how old a given formation may have been at such a time. To get at this problem it is necessary to ascertain the geological history of the region in which the prospect lies, since most areas have been affected by more than one dynamic disturbance, the number and geologic date of each should be carefully determined. Thus, it should be ascertained whether the formation which is looked upon as a possible oil or gas producer was old, and possibly compacted, cemented, or otherwise metamorphosed, before the supposed favorable structure was formed, for the physical condition of the prospective oil and gas rocks at the time of folding would have an important influence on the possible migration of hydrocarbons from their disseminated state to some concentration point where a pool may be formed.

Much depends upon the view adopted as to the time when the concentration of the oil and gas is accomplished, following the formation of suitable structure. Does it occur in a relatively short time, or is it more or less continuous and spread over several geological periods? The answer can only be found by referring to the age of the youngest petroliferous strata, and noting the time that can be definitely stated as having elapsed since the beds were laid down and the structures were formed in which we now find the oil and gas. The problem is not concerned with cases of migrations from older beds into the very recent ones along faults or fractures, but more especially with the indigenous occurrences of hydrocarbon deposits. Rocks as young as the Pleistocene carry oil in the Summerland and Puenta Hills regions of California, and gas is found in the Lake Bonneville beds of Salt Lake Valley, Utah. Strata of Pliocene age carry oil in California, and the Gulf Coast regions of the United States, and in Roumanian and Sumatra foreign fields. These very late rocks are not as prolific sources of oil and gas as are the middle and lower Tertiary formations, but they serve to illustrate the point that oil does form soon (geologically) after the deposition of the beds and collects into pools rather rapidly after the formation of suitable structure. That there remains behind a very large total amount of oil that is not concentrated into pools is well known from the almost universal presence of oil in most dark shales and limestones as tests have shown. Whether any of this remaining oil will ever be gathered into pools is doubtful, inasmuch as existing structures into which some oil has migrated have failed to effect complete concentration of all of the oil. The droplets of oil held in cavities of crystalline limestones are probably sealed up permanently, and oil absorbed in shale is kept from migrating by cohesion and capillary forces within the shales. However, at least enough oil is formed and does migrate in the late sediments to form commercial pools, and they show strikingly the general fact that many, if not all, of the known pools may have been formed in a similar way during the early history of the respective formations in which they occur.

Whether the general thesis here presented will be found to be true upon final study of all known pools cannot now be stated, but,

in a large sense, it seems to present interesting possibilities. The critical test comes when this line of reasoning is applied to deposits of oil and gas in the older rocks. With the exception of a minor occurrence of oil in the Lower Carboniferous strata of England, all occurrences of oil in Paleozoic sediments are confined to the fields of the United States. And in most, if not all, of these home fields there have been discovered evidences of crustal disturbances in those early times. In the Cincinnati arch region the uplifting began as early as the Ordovician, and large deposits of oil and gas are found in the Ordovician and Silurian rocks. In the Appalachian fields the oil and gas occurs in rocks of Devonian, Mississippian, and Pennsylvanian ages, and during these periods there were dynamic disturbances at various times, as shown by unconformities between the different systems and formations which carry the oil and gas, and which culminated in the well-known Appalachian revolution, in Permian time. The Ozark uplift and the Ouachita and Arbuckle mountains were raised at approximately the same time, and the oil of these regions is found in rocks of the different Paleozoic systems, commencing with the Ordovician (Simpson formation) which produces oil at Healton. In the Rocky Mountain fields, only rocks of late Paleozoic age have been found to carry important quantities of oil and under somewhat unusual conditions. The importance of these deposits in comparison with the light oils and gas of the Mesozoic formations is almost negligible, notwithstanding the fact that they are affected by the same structural conditions favoring oil accumulation, together with possible earlier folding as well. There is no marked unconformity between the Paleozoic and Mesozoic rocks, but there are many disconformities and undoubtedly there were minor warpings sufficient to form structures into which oil might be concentrated. Thus it appears that folds which are not in positions favorable for light oil accumulation, such as the so-called mountainward folds, do at times carry the heavy black oil in the Carboniferous and Permian rocks. And vice versa, folds favorable for accumulation of oil and gas in the Cretaceous rocks may be barren of oil in the older strata. These conditions are explained on the hypothesis of more than one period of folding, the black oil coming into the most favorably situated

structures of the first movements, and the younger light oils accumulating in the later structures which may be superimposed on the older ones, or developed in places where there were no previous folds. Reference to the diagrams, Figures 1 and 2, make this plain.

Figure 1 shows three anticlines in cross-section, a major and two lateral folds. Fold 2 s the largest and probably was the first to form, with 1 and 3 developing as secondary wrinkles along the flank of the major fold. Following the first period of deformation some erosion has occurred, with the removal of more sediment from the central and highest structure, and a reduction of the surface to an approximate plain. Folds 1 and 3 are in favorable positions for oil accumulation, having a large gathering ground on their basinward sides. The central and larger fold, however, has limited drainage area on both sides and may not accumulate a commercial pool. As represented, the oil sand having become saturated with oil in domes 1 and 3 (indicated by solid black areas) has been eroded off the top of the large dome, 2.

Figure 2 represents the same folds as figure 1, with added history. A later sedimentary series has been unconformably deposited over the eroded edges of the earlier beds, following which there has been further folding and subsequent erosion. Folds 1*a*, 2*a*, and 3*a* are the enlarged counterparts of 1, 2, and 3, in Figure 1, and fold 4 is a new development of the latest movement. The line of unconformity, shown by the heavy black line, marked *u* on the margin of the section, represents the former surface profile of Figure 1, and has been warped in accordance with the latest deformation, similar to the flexures of the overlying beds. The oil pools of Figure 1 are still preserved, though altered in form and position. Later accumulations of oil are shown in folds 1*a* and 4. Folds 2*a* and 3*a*, being inside, were in unfavorable positions with respect to the drainage basins outside of 1*a* and 4, and are, therefore, barren in the upper sands.

Throughout both of the periods of folding represented here, fold 1*a* remained an outside, or basinward fold, and has received oil accumulation both in the earlier and later rocks. The pool in the third or deepest sand is to be considered as distinctly older than

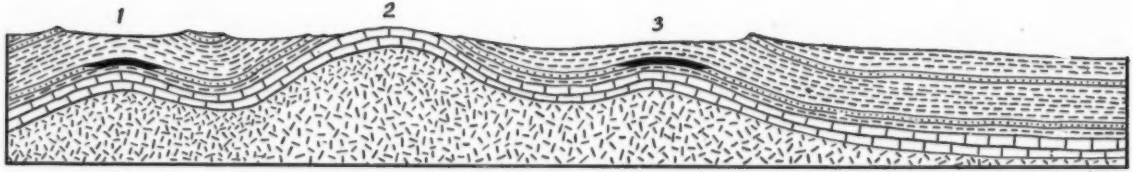

FIG. 1.—Ideal cross-section of a major anticline and two subordinate folds of same generation, showing accumulations of oil in the minor folds, and some erosion.

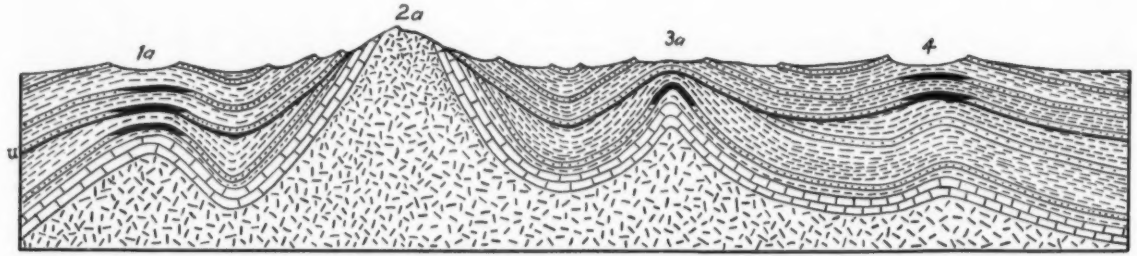

FIG. 2.—Same as Fig. 1, after deposition of later beds unconformably, and subsequent folding, oil accumulation, and erosion

the two upper pools, which came into existence following the last disturbance. The pools of fold 4 are of the same age as the upper two in 1*a*, and the pool of fold 3*a* is of the same age as the deep oil of 1*a*. The absence of accumulation in the deep sand on fold 4 is explained by previous migration to the pool shown in 3.

Conditions similar to these are to be found in various parts of the Rocky Mountain province, where major anticlines, often forming mountain ranges, are flanked by secondary folds. Oil and gas occurrences in these folds are subject to many irregularities difficult to explain without considering the different periods of crustal movement which have affected them. It is in general comparatively easy to explain the presence of oil or gas after a discovery has been made, but it is often difficult to analyze conditions in advance of drilling and predict the presence or absence of hydrocarbon deposits in a particular structure. There are other factors besides folding that have to be considered, most of which are less definite and cause more doubt and risk than structural conditions, so that considerations of structure cannot serve as a safe basis alone on which to predict future production. But a careful consideration of structural relationships may, and often does, suffice to determine whether the chances of finding new pools of oil and gas are good or bad in a given case, and it is to aid in such a study that attention is here called to the importance of time relationships, especially as regards periods of folding, to oil and gas accumulations.

The application of the foregoing principles to well-known examples in the Rocky Mountain fields may be briefly considered. In this province, as already pointed out, the Mesozoic deposits are of much greater economic importance than those of the older Paleozoic rocks. As yet no Cenozoic deposits of commercial value have been developed in the Rocky Mountains, though there are extensive saturated oil sands which are apparently independent of structure, and vast deposits of oil shale in which the structure does not play a controlling part, so far as present knowledge goes. As regards periods of folding, it is customary to consider the Rocky Mountain folds to be mainly of post-Cretaceous age, as rocks of latest Cretaceous age and earliest Tertiary are involved in the main folds. That there were later disturbances is plainly seen in

the tilted and often more gently folded beds of later Tertiary age. Marked unconformity exists between these beds and the Cretaceous and older formations, and, as represented in Figure 2, the plane of unconformity has been warped in a manner similar to that of the Tertiary strata themselves. Earth movements of a gentler type preceded the great Rocky Mountain folding, as shown by the presence of Dokata beds on Paleozoic or older strata in various parts of the province. Generally, along the principal mountan ranges of the Rockies, there is a marked apparent parallelism between the Cretaceous and older beds, but, in some of the parks, the Dakota seems to have overlapped the Mesozoic formations and covers Paleozoic and older rocks. This condition suggests the possibility that there were important warpings, perhaps folding movements on a broad scale in times prior to the Cretaceous period, which affected this province. The important disturbances of the Jurassic period, in the Sierras, may have produced folds of a gentle character, possibly sufficent to effect oil accumulation, in the late Paleozoic beds, then comparatively young, but not sufficient to produce marked local unconformity.

Figure 2 is intended to bring out this relation between the Cretaceous and older beds, and the unconformity there shown is purposely made of the pronounced type to emphasize the observed relationships. The newer pools represented here may simulate the light oil pools of the Rocky Mountain fields, and the older accumulations, below the line of unconformity, the black oil pools of the pre-Cretaceous beds. The different structural relationships shown will represent those of various fields in which either light oil, or black oil, or both have been found to occur. Thus, fold 1*a* may represent Grass Creek, where production is found in both the Cretaceous and pre-Creatceous rocks, and the oils are of a distinctly different character. Fold 3*a* may represent Hamilton dome, a mountainward fold, with production in the older rocks. Many examples of case 4 may be named, where the older rocks are barren of accumulation on apparently favorable structures.

SUMMARY

1. Oil and gas accumulate after the structure in which they are found has been formed.

2. The age of an oil pool is defined by the age of the structure in which it occurs, and not by the age of the bed in which it is found.

3. Oil accumulates comparatively soon after suitable structure is formed, and beds folded while they are young and unconsolidated favor accumulation.

4. Old beds affected by new, or late, structures, are of doubtful value in connection with oil prospecting.

5. In mountainward folds, affected by more than one period of folding, the beds involved in the first folding movements may have prospective value, while the later ones do not (case 3*a*).

6. In basinward folds, affected by one period of movement, the later rocks may have oil accumulation while the older beds are barren (case 4).

7. In basinward folds, affected by two periods of movement, both the older and younger beds may have production (case 1*a*).

8. In the Rocky Mountain fields, the various pools may be classified under one of the types, 1*a*, 3*a*, or 4.

DISCUSSION

J. M. DOUGLAS: It seems to me that we often do not give enough consideration to the vast amount of time that may be necessary for the formation of oil and gas structures. Is it not possible that oil is formed while the sediments are being deposited as well as during a later period when live oil may be formed from the formations that contain hydrocarbon matter, such as kerogen, whenever such formations are subject to heat or pressure or a combination of both. For example, if heat, pressure, or a combination of these, were sufficient on the rich oil-bearing Devonian shales in the east, oil would be driven off at the present date whereas it is possible that the Tertiary Green River shales of northwestern Colorado, eastern Utah, and southwestern Wyoming may not have been subject to enough heat, pressure or a combination of both to drive off enough oil to form commercially valuable oil pools.

It seems to me that oil may be formed when the containing rock formation is deposited or at any later date before the shales become schists, or at any period at which there is sufficient heat, pressure or a combination of both to drive off oil from the organic shales. Thus, oil may originate when the formation is deposited, or at any of the periods in which the formation is subjected to heat, pressure or a combination of both, till all the oil has been driven off and the formation is a schist.

MAX BALL: Mr. Douglas' suggestion that the amount of heat and pressure to which the Green River shales have been subjected has not been suffi-

cient to induce the production of oil is refuted by the amount of oil occurring at the surface in these shales, in several-dozen known seeps, some of these large, and by the oil obtained for twenty years or more from the Wade tunnel, where enough oil is produced to run a small refinery.

His statement that there are no oil fields in the Green River shales is true, but not the inference that none will be found. The series has not been sufficiently tested to show whether or not oil in commercial amounts is present. One well has been drilled on the Hell Creek structure and was dry. A well drilling on one of the Duchesne structures encountered water in its first sand at 2,690 ft., and has not yet penetrated the numerous deeper sands. This well has at least a dozen oil showings, some sufficient to cover the water in the sludge pit, and four gas showings, one or two of them good for 500,000 to 1,000,000 cu. ft. per day. No other wells have yet been drilled on favorable structures. It can scarcely be said, then, that the Green River shales contain no commercial accumulations of oil. In fact, the amount of oil produced from Wade tunnel and the number and size of live seeps indicate that where conditions for accumulation have been favorable commercial pools are likely to have been formed.

GLEN RUBY: It is to such variation in the age of folding that I attribute the failure of the wells on Salt Wash and Caineville, Utah, to find oil or gas. The present San Rafael Swell represents the Number 1 fold on the diagram. It shows clearly a considerable amount of late Triassic and early Jurassic folding by the thinness of these sediments on the crest of the eroded fold and a rapid thickening on the flanks. The wells mentioned drilled a much greater thickness than anywhere exposed. Since these two minor folds parallel the region of Wasatch faults rather than the axis of San Rafael Swell, it is probable that they are of Wasatch age and the oil left the territory which they involve as soon as the Jurassic folding made its effect on all the territory adjacent to the Swell. Thus these minor folds on the flanks of San Rafael Swell can be likened to fold Number 3 with the beds involved being the lower one in the diagrams. When these folds were formed there was no oil left in the underlying sands to be trapped. It had been migrating since Jurassic time and accumulated in the now eroded sandstones of San Rafael Swell.

GEOLOGICAL NOTES

SUGGESTIVE EVIDENCE ON THE ORIGIN OF PETROLEUM AND OIL SHALE

There is a growing tendency among petroleum geologists to picture the original source of petroleum as organic muds. The oil shales are frequently cited as possible analogous deposits although it is well known that they contain little or no material soluble in chloroform or other solvents of petroleum. Some years ago the writer was studying the history of Lake Lahontan and as a by-product observed certain occurrences of algae that seemed to give a clue to the relationship of oil shales and petroliferous sediments.

Lake Lahontan was an enlargement of the present lakes of northwestern Nevada and covered an area of about 8,500 square miles. Our present evidence indicates that it began as a fresh-water lake about 2400 years ago and reached its maximum depth about 1000 A.D. As the ancient lake had no outlet, salts gradually accumulated until the present Pyramid Lake, one of the largest remnants of Lake Lahontan, has a salinity of 3,500 parts per million.

The first well drilled in the Lahontan sediments by the United States Geological Survey in the search for buried deposits of potassium salts, was bored near Fallon, Nevada, in Sec. 30, T. 21 N., R. 30 E., Mount Diablo base and meridian. The well reached a depth of 935 feet, and the published log[1] of the upper 835 feet shows alternating beds of sands and clays of lacustrine origin. Oil spots in the sludge water are mentioned as indications of petroleum at five horizons, respectively 125, 135, 155, 278 and 297 feet below the surface. The first three horizons are associated with dark colored quick-sands. Hydrogen sulphide occurs in a sand at 85 feet and in water flowing from a sand at a depth of 225 feet. The dark colored sands occur between 77 feet and 155 feet, while dark to black clays occur at 100, 150, 158, 175, and 310 feet. Aside from the occurrences mentioned, the clays and sands are light colored or bluish green. The noteworthy facts are that the oil spots and dark colored sands and clays are confined to the upper portion of the lacustrine sediments and are largely found only in the upper 150 feet.

[1] H. S. Gale, *U. S. Geol. Survey, Bull.* 530 (1913), pp. 306–11.

Paul Butler drilled three wells for water about a mile east of Flanigan, in Sec. 36, T. 27 N., R. 19 E., and in all three wells encountered sand at a depth of 160 feet which contained enough bitumen to partially cement the sand when heated. This was in an arm of the valley that contains Honey Lake, and connects through Astor Pass with the valley in which Pyramid Lake lies. The sands are a part of the Lahontan sediments and are typical beach sands. An examination of the sands under a microscope disclosed bits of solid, jet-like fragments of bitumen together with small particles of woody vegetation and partially decomposed algae. Chloroform extracted about 30 per cent of the material in the sand sample, and on evaporation of the extract a solid, black, glossy wax-like substance remained which melted when heated. Unfortunately the amount available was insufficient for an analysis. Mr. Butler states that when the sand was encountered considerable gas with a disagreeable odor was given off and as nearly as can be judged from his description it was largely hydrogen sulphide.

In wells drilled in other parts of the Lahontan basin, comparatively fresh algal fragments in paper-thin greenish flakes up to one inch in diameter have been encountered in the clays at depths below 300 feet. The significant data are that the organic material deposited during the early history of Lake Lahontan and while its waters were fresh are but partly decomposed, while the decomposition of the organic material found in the upper lake beds has progressed sufficiently to give traces of petroleum.

At the north end of Pyramid Lake, algae of the genus *Gleocapsa*, grow attached to the sandy bottom at depths of 10 to 25 feet. They are dislodged by storms, float on the surface of the lake, and are drifted to bays at the extreme northern end of the lake. There they become intermingled with the beach sands forming more or less lenticular pockets that are very rich in algae. On stepping out of a boat on to these algal sands, one sinks frequently to his knees, and the disturbed sands give off a strong odor of hydrogen sulphide. The sands are black, due to the partial decomposition of the algae.

In order to determine whether the true explanation of the traces of petroleum found in the upper 300 feet of the Lahontan sediments lies in the present accumulation of the algal sands, four samples were taken as follows: (1) a sample of the fresh algae as they had accumulated on the surface of the beach; (2) sands as free from algae as possible to obtain; (3) from a layer one foot deep in the beach sands, black in color and with abundant remains of decomposing algae; and (4) of material similar

to sample (3) at a depth of two feet from the surface. The samples were submitted to M. R. Miller, chemist for the Nevada Experiment Station, who leached them with chloroform with the following results:

ANALYSES OF LAKE LAHONTAN ALGAE AND SAND SAMPLES

Sample Number	Loss on Ignition	Chloroform Extract	Chloroform Extract on Residue Free Basis
	Per Cent	Per Cent	Per Cent
1	80.80	0.59	0.73
2	3.90	0.005	0.128
3	11.89	0.26	2.18
4	4.48	0.23	5.13

It is evident that even within the shallow depth of burial the relative amount of material soluble in chloroform increases. On evaporating the chloroform extract of the last two samples a black, waxy residue was obtained quite similar to that recovered from the sands of the Butler wells.

The hint that is given by these isolated observations is evident. While the lake was comparatively fresh, the algae and other organic material included in its early sediments were but partly decomposed. In time, when these beds are consolidated, they will form oil shales. During the last few hundred years of the lake's history its waters have become increasingly saline. Eventually the concurrent increase in the relative amount of decomposition of the organic material has reached the point where petroliferous material has begun to form. Perhaps this point may be better impressed on the reader if the characteristics of oil shales and organic muds now forming in saline waters are compared and contrasted.

In a recent publication, Gavin[1] has summed up our present knowledge of the nature and origin of oil shales. He defines an oil shale as "a compact, laminated rock of sedimentary origin, yielding over 33 per cent of ash and containing organic matter that yields oil when distilled, but not appreciably when extracted with the ordinary solvents for petroleum." One of the most striking characteristics of oil shales is that while they contain slight amounts of material soluble in chloroform and other solvents of petroleum, by far the greater portion of the kerogen requires distillation before it can be considered as petroleum. The oil shales contain little or no oil as such. Several investigators have studied the shales under a microscope and have agreed that the kerogen consists

[1] Martin J. Gavin, *U. S. Bureau of Mines, Bull. 210* (1922), pp. 26–38.

of vegetal débris somewhat decomposed by bacterial action and resembling certain phases of peat. Gavin[1] cites an instance of the recent formation of an oil shale in Brazil. Here a 20-foot well was sunk in marshy ground that had many water pools and abundant vegetation. The well was dug through alternating layers of black and brown muds and below 16 feet the muds were laminated and entirely similar to the oil shales found in the vicinity.

The oil shales are usually considered as rather closely related to the cannel and boghead coals. Most investigators have concluded that these coals were formed chiefly from spores accumulating in areas of open water in the midst of the coal marshes. The oil shales in Nevada, however, are more closely related to the lignite coals that are interstratified with them, the only difference being that the coals contain chiefly woody vegetal material while the shales are chiefly algal in origin. The kerogen of the oil shales of the Mississippi River Basin were found by Thiessen[2] however, to consist largely of plant spores, definitely connecting the shales with the cannel coals of the region.

In discussing the origin of cannel coals Moore[3] cites certain data from Russia that is similar to the evidence from Lake Lahontan. In a brackish shallow lake the algae contained 3.5 per cent of oil and the crust forming along the shores was 25 per cent soluble in ether. Evaporation of the ether left a hard, waxlike mass.

Hydrogen sulphide is given off during the fermentation of the algal mass as at Pyramid Lake and thin sections show a slight amount of the cellular structure of the algae remaining.

It has long been recognized that saline waters were necessary for the formation of petroleum. This point is emphasized by Schuchert[4] in a discussion of petroliferous provinces in which he especially excludes strata of continental or fresh water origin from petroliferous areas. According to White[5] the rôle played by the salt in the formation of petroleum is yet to be demonstrated. He emphasizes the efficiency of bacterial decay in salt water as well as in waters that are fresh.

If it be permitted to outline a tentative hypothesis based on the scanty evidence at hand, it would be as follows: Oil shales originate as fresh water muds containing a large percentage of spores, algae and other non-woody vegetal material which has been partially decomposed by

[1] *Op. cit.*, pp. 37–38.

[2] R. Thiessen, *Bull. Geol. Soc. Amer.*, Vol. XXXII (1921), pp. 72–73.

[3] E. S. Moore, *Coal*, John Wiley and Sons (1922), pp. 176–77.

[4] Chas. Schuchert, *Trans. A.I.M.E.*, Vol. LXV (1921), pp. 204–16.

[5] David White, *Bull. Geol. Soc. Amer.*, Vol. XXVIII (1917), pp. 727–34.

bacterial action, but not sufficiently to raise appreciably the relative proportion of fats through removal of the other plant substances. The origin of petroleum is in muds, sands, and calcareous muds deposited in saline waters and containing a considerable percentage of organic matter, which is largely algal in origin but may in special instances consist chiefly of other plant and animal remains, which have been so thoroughly decomposed through bacterial action that the fats form a relatively high percentage of the organic material remaining. In other words, the chief difference in the origin of oil shales and sediments giving rise to petroleum lies in the degree of bacterial decomposition of the organic matter which in turn depends on the saline content of the waters in which the decay takes place. In fresh water the decay is relatively slight, while in salt water it is nearly complete. If our evidence from the Lahontan basin is of value, the dividing line between the fresh waters producing oil shales and the salt waters forming petroliferous sediments lies somewhere near a salt content of 2,500 to 3,000 parts per million.

If this hypothesis proves true it will give a clear picture of the relationship between coal, oil shale and petroliferous sediments. In fresh waters only coals and oil shales will form, for the bacterial decay does not remove a sufficient amount of the tissues of the plants nor appreciably act on the fats to produce petroleum. When the salinity of the water rises above 3,000 parts per million the character of the bacterial decay is such as to eliminate largely the greater part of the organic matter and change the fats to petroleum.

White[1] has definitely shown that there are two stages in the formation of coal. The first, the biochemical stage, covers the change of the original vegetal material through bacterial decay into lignite; the second, the geochemical stage, transforms the lignite into the higher grades of coal through augmented heat and pressure resulting from diastrophism. He further recognizes[2] that petroleum probably passes through the same stages but conceives that the oil shales represent the biochemical stage. If the hypothesis here proposed be correct, we should look for the original source of petroleum in the organic sediments of saline waters and recognize that only in rare instances where oil shales are brought into regions of high temperature, such as igneous intrusions, is there any possibility of petroleum being distilled from them.

The crucial evidence of the biochemical stage in the origin of oil shales and petroleum will be found in a thorough study of the processes of

[1] David White, *U.S.B.M., Bull. 38*, 1913.

[2] David White, *Bull. Geol. Soc. Amer.*, Vol. XXVIII (1917), p. 732.

organic decay in fresh, brackish, and saline water. Such a study will demand the best skill and technique of chemists and bacteriologists as well as geologists and at its conclusion it is believed that the present puzzling relationship of oil shales and petroliferous sediments will be explained.

J CLAUDE JONES

THE "RIM ROCK" OF THE HIGH PLAINS

There is a general impression that oil geologists lack opportunities to do much for the advancement of pure science. This impression is false as well as harmful. While it cannot be denied that some oil geologists may sometimes express themselves as being indifferent to "theoretical" subjects, the writer is of the belief that this attitude neither is general on the part of the profession nor more than superficial in the cases where it appears. It seems to him that oil geologists not only have good opportunities for aiding in the advancement of general geology but that they also have used these opportunities in the past. This helpful attitude should be encouraged. To do his share in such encouragement, may the writer ask indulgence for calling attention to a subject, to the knowledge of which important help may be given just at the present time, by oil geologists who have worked or who may be called upon to do work on the plains and high plateaus of the Southwest?

There is a formation in the Southwest, the nature and origin of which is not as well known as it should be. It is known by different names such as caliche, tepetate, surface marl, rim rock, lake marls, scarp rock and cap rock. To the present writer it appears that all of these different designations refer to deposits that are in one sense a unit: their origin is similar. They should be considered a unit whatever variations they may display. Such variations may be very considerable. Caliche usually consists of calcareous material or ranges from an admixture of calcareous material in clays and silts to almost pure calcareous rock, or limestone, in certain places. Again, similarly made deposits may consist, not of calcareous, but of siliceous material. The chemical composition of these deposits appears to have a great range. In some places they consist of highly ferruginous material and almost any ingredients occur that are found in the formations immediately underneath the caliche. There have come to the writer's attention small deposits of saltpeter evidently formed in the same manner as caliche.

The present writer believes that the rim rock, or cap rock, which appears in the escarpments bordering the high plains on the west as well as to the east, in New Mexico, Texas, Oklahoma and more interruptedly farther north, has an origin like that of the well-known caliche which occurs in discontinuous patches on the lands of dry climate in the Southwest. From conversations he has had with other geologists he believes that he is not alone in entertaining such an opinion. It seems that the earliest geologists who passed across the western plains regarded this rock as a deposit made in late fresh water Tertiary lakes. The "rim rock" in Texas is a white, soft limestone frequently quite pure, but usually containing some grains of fine sand and silt. It has a peculiar bedding, showing flowing lines of discontinuous finer lamination. It measures from less than five to more than twenty feet in thickness. Its resistance to weathering is the cause of the presence of high escarpments traversing the east part of the Panhandle and eastern part of the Llano Estacado. The same escarpment is seen in many places in southeastern New Mexico. This escarpment was first mapped by Cummins in his report on the Panhandle and the Llano Estacado. The deposit is usually overlain by sediment from ten to twenty feet in thickness. This overlying sediment varies greatly in thickness and is in some places absent, exposing the limestone in the interior of the plains.

It is quite generally understood that caliche consists of material which has been brought up in solution to the surface from the underlying formations by water which rises by capillarity to replace such water as is being evaporated from the ground into the air in dry climates. Caliche is, therefore, a precipitate from aqueous solutions rising from below. Where the underlying formations are rich in ferruginous material, the caliche may contain, as its largest ingredient, oxide of iron. Some laterite may have been formed in this manner. For the formation of caliche, a climate is required that has long, dry seasons, alternating with shorter intervals of considerable rain. After a heavy rain, the water will percolate down into the ground. This water no doubt dissolves some of the surface material to perhaps again precipitate this some distance below the surface, or else carry the calcareous material in solution wherever the water percolates under ground. Again, during long droughts, evaporation at the surface will result in a slow rising of the ground water to replace the evaporated water. As the water evaporates at the surface, anything carried in solution will necessarily be deposited by precipitation in the interstices of the surface soil. Different physical conditions, and perhaps differences

in the dissolved ingredients, will determine whether the deposit thus formed by precipitation will make a soft powder or a solid coherent mass.

It is conceivable that during long spells of evaporation the ground moisture may be evaporated to a considerable distance down below the surface. Especially favorable for such deep evaporation, it appears to the present writer, would be the existence of a superficial deposit of a very porous kind, such as would result from an accumulation of loess. The yellow "clay" which overlies the rim rock in the Panhandle has probably been such a deposit. At the present time it is in many places quite impervious to water, owing to infiltrated ferruginous and fine clayey material. But this may very well be a secondary characteristic, acquired after the making of the rim rock. If at some time in the past the water table, or, if the term be permitted, the ground moisture table, was maintained at the level where we find the rim rock, this might account for its deposition. The level down to which evaporation extended would naturally be the level at which precipitation of the ground water solvents would occur. If such an explanation of the origin of the rim rock is true, it should be possible to find some field evidence for its support. This evidence will be difficult to collect, owing to the fact that good sections showing the relation of the limestone to the loess and to the underlying formations are rare. The present writer has seen some sections which suggest that the cap rock, at least in the interior of the plains, bears some relation to the present topography. Instances are known where two cap rocks occur, one above the other. The cap rock, as it were, splits into two layers, with some intervening loess-like material. Phenomena of this kind may be accounted for on the theory of changes in the local topography caused by progressive erosion or by continued accumulation of loess. Such changes would naturally bring about changes in the depth to the ground moisture table and thus give rise to more than one stratum of "rim rock."

If the writer may make a suggestion to those who may have an opportunity to examine lands in the Panhandle and in the Llano Estacado, it would be this: That notes be taken on such details of the stratigraphy and the characteristics of the formations of this kind as may come under observation. Such details should be preserved by the publication of brief notes in geological journals. In time, sufficient material may accumulate in this way to be adequate for a general discussion on good foundations of the origin of the cap rock.

J. A. UDDEN

SOME PROBABLE RELATIONS OF STRUCTURE TO PRODUCTION IN KANSAS

One is impressed by the lack of the discovery of any oil to amount to anything on the enormous Dexter and Beaumont-Eureka anticlines. This seems to be mainly due to the lack of deposition of the sand generally referred to as the Bartlesville, from which most of the production adjacent to these anticlines is obtained. The larger part of the work of the geologist in Kansas is in locating these areas of favorable sand deposition.

It appears that between the deposition of these sand bodies and the structures some very definite relations may be carried out, and that by the applying of the principles to other places other bodies of sand may be found.

A fact that appears to have great significance is that the Sallyards-Blankenship pool is almost north of the bend in the Beaumont anticline southeast of Beaumont or in an almost exact prolongation of the course of this structure before it takes its northeastward trend. Something of a similar nature may be observed as to the location of the pool of the Phillips Petroleum Company in T. 35 S., R. 7 E. in regard to the Dexter anticline, although this pool is east of the Dexter anticline and in line with the northeastern prolongation of the anticline before it takes its northward course. Some production was being obtained from supposedly Bartlesville sand, but the value of this horizon had not been definitely proved at the time that this study was made in December, 1921.

To explain these facts it is reasonable to assume that the winds during the Cherokee time were about the same as at the present, as the meteorological conditions that controlled the trade and westerly winds must have necessarily been the same then as now. Kansas then lay in the belt of the westerly winds. Another assumption is that during the deposition of the Bartlesville sand these structures were slightly folded and elevated to form low-lying narrow islands. The writer was unable to prove a thinning of section in the Cherokee shale over these structures in Cowley County, due to the lack of well-defined horizons. Near Eureka there may be a very slight thinning in the Pennsylvanian sediments over the structure, and Sallyards shows a thickening in the Cherokee shale which tends to prove this point.

The westerly winds would set up waves which, when striking these shores obliquely, would form northerly moving currents parallel to the shore. When the shore line turned to the east the current would leave

the shore line and deposit its load of sand, thus being a means of concentrating the sand of the mud-laden waters of Cherokee time.

Sand bodies to the east of these islands would be formed at the prolongation of an eastward shore line opposite the point where it turned to the north. These shore lines, however, would be very inefficient as a means of setting up currents as they are, in these two structures, generally very short before a northward trend is again made. They generally run in a direction about parallel to that in which the winds blew, and were also on the sheltered sides of the islands.

A third means of forming sandbars and in reality a modification of the first method would be where an island terminated. If there should be another island to the north and west of the termination of the south island a bar would be formed to the east or on the sheltered side of the north island. Such a probable place would be to the north of Dexter in the region between Grand Summit and the Beaumont anticline.

A fourth means of setting up currents would be the ebb and flow of the tides between islands and we should look for bars to be discovered opposite such places.

No attempt has been made to locate the origin of the sediments forming these bars as it seems that all over this portion of Kansas the waters of Cherokee time were sufficiently mud-laden so that all that is needed is a separation and concentration of the sands.

J. Boyd Best

Shreveport, La.

WATER CONDITIONS IN CURRIE, TEXAS, OIL FIELD

Preparatory to an investigation of underground water conditions in the Currie oil field in Texas, a large number of well logs and other data have been collected by the United States Bureau of Mines from operators in this field. Material for a peg model of the more intensely developed portion of this field is in preparation. The new wells in the Richland District—north end of Currie Field—are developing aggravated water troubles. Several conferences have been held with operators in this district. Two samples of oil, one from Richland and one from Currie, were analyzed at the Pittsburgh laboratory. Both samples yielded a high percentage of the light fractions but also a high carbon residue.

WATER CONDITIONS IN MEXIA, TEXAS, OIL FIELD

The experimental work on the small group of wells in the northern part of the Mexia, Texas, oil field, or "Fish Pond" area, being conducted by the United States Bureau of Mines, has been extended to cover a larger area. The correlation for this area has been completed and indicates some trouble from bottom water as well as edge water in a portion of the area, also some trouble from faulty and non-uniform shut-offs. The correlations will be extended into two adjacent areas, both of which are producing large quantities of water, to check on the bottom water. A circular letter has been sent to Mexia operators outlining methods for the protection of the upper oil-bearing horizon, in wells which will be drilled to the deeper production, discovered in Humphreys Oil Company well Kollman No. 9. No other wells have been drilled into the deep production. One well in the extreme southern portion of the field was drilled through this horizon and did not encounter oil. It is drilling deeper for a test of the Trinity horizon. One well in the northern portion of the field is setting casing at about 3,200 feet and will be drilled into the Kollman No. 9 horizon soon.

OIL SHALE INVESTIGATIONS OF UNITED STATES BUREAU OF MINES

Assay tests on a sample of Brazilian "turfa" have been completed at the Boulder, Colorado, field office of the United States Bureau of Mines. This material is a soft brownish-yellow substance, having an apparent specific gravity less than that of water. It yields on distillation as much as 113 gallons of crude oil of 0.870 specific gravity, and in addition up to 6 gallons of scrubber naptha per ton. The oil is of very good quality as shale oils go, and the material also gives a relatively high yield of gas. In retorting, the turfa shrinks to about one-third of its original volume, and forms a weakly adherent coke of probably fair fuel value. The effect of rate of oil production on the quality of oil is shown up very strikingly in the examination of this material. For example, gasoline produced from oil made from this material at the rate of 1 c.c. per minute was 34.0 per cent unsaturated, while the kerosene fraction of this oil was 41.5 per cent unsaturated. From crude oil produced at the rate of 0.2 c.c. per minute, the gasoline produced was 30.1 per cent and the kerosene 33.6 per cent unsaturated.

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In the general survey of the oil shale resources of Indiana, being made by the United States Bureau of Mines, in co-operation with Indiana University, a study has been undertaken of the geology of the oil shale districts of Kentucky. Samples of Kentucky shale have been taken for purposes of comparison with Indiana shales. In nearly all respects the Kentucky shale is the same as that of Indiana, but the Kentucky (Chattanooga) shale has more of the non-oil-yielding materials, there being frequent layers of gray, brown, and sandy shales, lime, black shale, and an occasional band of chert. Data have been obtained on transportation facilities in the shale district of Kentucky as well as information regarding timber and water supply.

At the Boulder, Colorado, office of the Bureau of Mines, a chemical examination of oils produced from Colorado shale with the vertical retort has been begun. The first part of the work is an attempt to make a separation of hydrocarbons into the different organic series by means of selenium oxychloride.

OIL DEVELOPMENTS OF 1922 IN ILLINOIS

ILLINOIS PETROLEUM PRODUCTION IN 1922

The production of crude petroleum in Illinois during 1922 was 9,359,000 barrels compared with 10,044,000 barrels in 1921, a decline of 6.8 per cent.

Somewhat offsetting the natural decline of production in the wells of the older fields, 341 new wells were drilled during the year. Of these 89 were dry holes, the remainder resulting in a total flush production of 5,893 barrels per day. This is at a rate of 23 barrels per new producing well, or 17 barrels per well drilled, including the dry holes which amount to 35 per cent of the new producing wells. During the same period, 71 wells in the older fields were abandoned.

RESULTS OF NEW DRILLING

Old fields in southeastern Illinois.—Of the 118 wells drilled in the old main fields in Lawrence, Crawford, Clark, Cumberland, and Coles counties, on the La Salle anticline, 82 were producers, with a flush production of 11 barrels per well drilled, or 16 barrels per producing well. The number (36) of dry holes drilled in this field is 44 per cent of the new producing wells.

Martinsville area.—On recommendations of the State Geological Survey a deep test was put down to the Trenton at about 2,500 feet in an old shallow producing area in Martinsville Township, Clark County,

resulting in a production of 125 barrels flush and about 25 barrels settled. This opened up probabilities of deeper production on a local structure previously outlined by the shallow drilling. The next deep test was being drilled in June, when at a depth of 1,325 feet oil was found in the Kinderhook beds immediately above the chocolate Sweetland Creek shale in what has since become known as the Carper sand. Production from this well settled from 150 to 25 barrels in a week, but at the end of six months it is still about 20 barrels. This is a new producing horizon for Illinois. During the latter part of the year, 9 wells were brought in at this horizon, and 2 dry holes drilled, one of which, located on the edge of the old shallow field, was drilled as a Trenton test. From these wells, the Carper sand has given a flush production of 59 barrels per well drilled, or 72 barrels per producing well, with the number of dry holes 22 per cent of the producing wells. Production is probable from this sand as well as from the deeper Trenton over an area of approximately 1 square mile.

Centralia field.—In the Centralia area, Marion County, and extending into Clinton and Washington counties, an active drilling program has been carried on throughout the year—particularly intensified when it developed into a town-lot proposition at Womac. The production, in what has been called the Petro sand in the basal Pennsylvanian, at a depth of approximately 750 feet, is associated with the same general structure reported on by the Survey in 1917,[1] and on which the Sandoval and Junction City pools were developed. About 2 square miles of producing area have been opened up by the drilling of 149 wells, of which 25 were dry, giving a total flush production of 26 barrels per well drilled, or 32 barrels per producing well, and the number of dry holes is 20 per cent of the producing wells.

Waterloo area.—Continuation of the drilling of the Waterloo field in Monroe County originally brought in following the Survey's published recommendation and report in 1920 has resulted in small, inside wells, but dry holes at the edges and wildcatting off the structure have reduced the results of the year's drilling of 12 barrels flush production per producing well to 7 barrels per total new wells drilled. The number of dry holes drilled was 80 per cent of the 15 producing wells.

Vicinity of Decatur.—Early in 1922, a short distance from Decatur, Macon County, a good show of oil was obtained in the top of the Devonian-Silurian limestones immediately underneath the Sweetland Creek shale. The well was reported with 25 barrels flush, but it did not

[1] Stuart St. Clair, "Centralia Area," *Ill. Geol. Survey Bull. 35*, 1917, p. 67.

pump sufficient oil to make a commercial well at that depth, namely 2,000 feet. Interest was aroused in this area, and another well was drilled in the immediate vicinity, testing both the Devonian-Silurian horizon and the deeper Trenton at 2,600 feet, and finding a good show of oil in both. Another well was drilled to the upper horizon in the same area and again found only a good show. Tests farther west that are being contemplated will show whether a commercial amount of oil is to be found on the structural terrace in this area, the presence of which was suggested by a State Geological Survey press bulletin published early in the year.

Macoupin County.—In Macoupin County two small areas have received systematic development of a shallow basal Pennsylvanian, probably the Litchfield sand, although the resulting wells are only light producers. Drilling on a small dome near Gillespie, determined from structure on a coal bed, resulted in a reported flush production of 45 barrels from 9 producing wells or 5 barrels per well. Including the number of dry holes (6) drilled, which was 67 per cent of the number of producing wells, the production figure is 3 barrels per well drilled. Another small local structure was drilled to about the same horizon in Carlinville Township and resulted in 13 barrels from 8 wells, one of which was a dry hole. This is equivalent to 1.6 barrels per well drilled, or 2 barrels per producing well. The number of dry holes is 14 per cent of the producing wells.

Jacksonville area.—Near Jacksonville in Morgan County, one or two light producers of oil and gas were drilled in an old partly abandoned field which has produced small quantities in the past. One test was drilled deeper to the Trenton but was dry with a slight showing of oil beneath the Sweetland Creek shale in the Devonian sand and limestone at about 800 feet. The State Geological Survey made a study of this area and in the near future will publish a report covering the occurrence of oil, and the possibilities for finding oil in commercial quantities.

Ava-Campbell Hill area.—The Ava-Campbell Hill structure in Jackson County has been a good producer of gas for some years. Oil had been encountered in several wells in the past, but never pumped until recently, when a well was brought in with a reported flush production of 125 barrels followed by a second with 50 barrels and a third with less production. These are probably in a lenticular sand above the original gas sand and lower down on the southeast flank of the north end of the anticline. A prospective area following this structural contour is thus

opened up for development. Recommendations to drill the southeastern flank for oil were made in *Bulletin 35* of the State Geological Survey.[1]

Friendsville field.—In December much attention was attracted to the vicinity of Friendsville, Wabash County, where a wildcat well southwest from the old development in the Allendale field and northwest from Mt. Carmel found a good pay at 1,530 feet, probably in the upper Chester formations, reported as pumping 300 barrels per day for the first two days. This opens up good probabilities for another local pool in this area.

Illinois wildcat drilling in 1922.—During the year there have been drilled numerous other wildcat wells in the state which, however, proved unproductive. Although some of them were well-advised tests, it is to be regretted that many operators still drill without making use of available geological facts, or consulting those qualified to give the geological advice on which oil development should be based.

WORK OF THE ILLINOIS GEOLOGICAL SURVEY

The work of the State Geological Survey relating to oil has been divided between laboratory studies and preparation of reports, and field investigations and surveys. A bulletin has been prepared covering in great detail paleogeographic, stratigraphic, and structural studies of the northern portion of the old fields on the La Salle anticline in southeastern Illinois, and including the application of theories of oil accumulation to the oil occurrences in Illinois.

A detailed survey, collection of statistical data, and study of the central portion of this old field have been undertaken but are not yet completed.

In the western part of the state a detailed structural survey and stratigraphic study have been made of Jersey and parts of neighboring counties, and a similar reconnaissance made along the Illinois and Mississippi rivers in co-operation with the Missouri Geological Survey. A survey of the field and study of the oil occurrence near Jacksonville have also been made and the report will be published shortly.

Co-operation with the producers regarding special problems and with wildcat drillers and other operators interested in drilling for oil and gas has been maintained through correspondence and personal investigations in the field.

PROSPECTS FOR OIL PRODUCTION IN 1923

The results of oil development in Illinois during 1922 have not been spectacular, but on the whole are fairly satisfactory, considering the fact

[1] *Op. cit.*, p. 57.

that outside the older main fields on the La Salle anticline most of the other structures in the state are of local and minor significance. Only fields of small areal extent resulting from local accumulation of oil can be expected.

The prospect for new production in 1923 is no less than at the beginning of 1922. The price of crude oil, which at present is fifty cents lower has an upward tendency and probably will not have a deterring influence on wildcatting.

With prospective areas for development recently opened up by the discovery of good wells, and with some wildcat drilling probable, 1923 should see a maintenance of new production in Illinois, thereby offsetting in a measure the steady but very slow decline of the older Illinois producing fields.

D. M. COLLINGWOOD

January 1, 1923

DRILLING IN WESTERN CANADA

(*Engineering and Mining Journal-Press*, August 12, 1922)

Wildcat drilling in Alberta and Saskatchewan in 1922 met with but little success. Five wells are being drilled by the Imperial Oil Company in central and southern Alberta and two in Saskatchewan. At the time of last report the tests in Alberta ranged in depth to 2,518 feet and showed only a small amount of viscous black oil, and in one well near Wainright, and another in the Pouce Coupe district, some gas. One well at Unity, Saskatchewan, was abandoned at 2,905 feet and another well in southeastern Saskatchewan showed no results down to 3,500 feet.

The Imperial Oil Company is carrying on exploratory work in the Fort Norman field. The discovery well makes a few barrels of oil per day but not enough to furnish fuel for drilling other wells. Numerous difficulties have hindered drilling operations but three wells have depths of 300 feet, 500 feet, and 1,735 feet, respectively, with no favorable results indicated.

J. H. HANCE

REVIEWS AND NEW PUBLICATIONS

The Marine Kerogen Shales from the Oil Fields of Japan, A Contribution to the Study of the Origin of Petroleum. By JUNICHI TAKAHASHI. Science Reports of the Tohoku Imperial University, Sendai, Japan, 1922. Series 3, Vol. I, No. 2, pp. 63–156.

This most valuable contribution to the knowledge of oil field shales begins with a very brief outline of the distribution and geology of the oil fields of Japan, the oil-yielding rocks of which are referable to the Upper Tertiary, probably the Miocene and Pliocene. The prolific oil deposits are found in, and even considered to be derived from, the series in which three species of shale predominate. In the normal sequence, *sandy* shale is found in the uppermost horizon of the oil measures, underiain by *gray* shale, and finally at the lower horizon by *black* shale. These shales contain remains of marine organisms and some organic matter which yields oil on distillation and they are therefore tentatively described as "marine kerogen shales."

Following this general summary, the author gives a rather detailed description of several different shales, illustrating with photomicrographs. Then follows a description of his method of testing the shales for oil yield and the tabulated results of the proximate distillation tests on 125 miscellaneous samples of shale from the oil fields of Japan. The results of distillation tests and microscopic examination of cuttings from several oil wells are given on pages 88–93.

There follows then, a detailed description of the shales from different localities in the Japanese oil fields, calling attention to the megascopic character, chemical character, mineralogical make-up, fossils, and the nature and occurrence of the kerogen (pp. 97–118). The author devotes seven pages to a discussion of the analyses of kerogen from the Japanese marine shales and kerogen from shales of fresh-water origin, and summarizes by stating that "a part of the extract from lacustrine shales when precipitated from chloroform, separated out as hard, elastic materials resembling resin, while no such precipitate is formed from the marine kerogen shales." "The fact that the distillates from the terrestrial kerogen rocks contain a comparatively larger amount of unsaturated hydrocarbon than those from the marine kerogen rocks, appears to be responsible for the larger content of resins, which produce unsaturated hydrocarbons on distillation."

In addition to the eleven plates of photomicrographs illustrating the character of various shales, including shales from China, Mexico, Scotland, and the United States, as well as from Japan, the author adds two extremely interesting and instructive plates, showing the relation of oil seats, micro-organisms, kerogen, and the size of the sand grains in six wells of the Japanese oil fields.

In final summary, Dr. Takahashi concludes that the original matter contained in the shales of a sapropelic nature is found in two principal forms—one carbonaceous and the other bituminous; that the bituminous matter has originated from the primary constituents of the shales and has not been introduced from foreign sources after sedimentation; that the kerogen of the Japanese oil-measure shales is chemically different from that of ordinary oil shale to a great extent; and that the Japanese oil measures "consist mostly of pyroclastic sediments intercalated with marine sapropelic shales containing a little kerogen. It is suggested that the oil originated, to some extent, from nectons and kelps which had been repeatedly buried by ash and detritus from submarine volcanoes, but largely from sapropelic ooze through subsequent dynamochemical changes. The marine kerogen shales are nothing else than hardened (dehydrated) and partially debituminized sapropel ooze. The brine and bitumen thus squeezed out from the ooze will migrate into porous beds so as to accumulate in pools."

Dr. Takahashi has carried on an extremely valuable piece of scientific research and deserves great credit for having given us such a complete summary of his data. In this day when "Oil Is King" it behooves every geologist who is interested in the search for oil pools to know as much as possible regarding the formation of oil, as well as regarding the factors which influence its accumulation and therefore the publication of the results of such research as this is exceedingly valuable.

DEAN E. WINCHESTER

Automatic Bailer for Oil Recovery. Engineering and Mining Journal-Press, August 19, 1922.

This article gives a detailed description of the construction and operation of an automatic bailer which was designed to make possible continuous bailing and obviate loss of time and production where certain wells had to be pulled and cleaned every few days because of heaving sands. The bailer is 4 inches in diameter, 50 feet long, and holds approximately one barrel of oil, and is operated by an assembly on a motor truck.

As principal advantages of the automatic bailer, it is claimed that (1) by continued bailing the well is kept clean, and the expense of pulling and replacing tubes, rods, and pumps is avoided, and that (2) the bailer has a swabbing effect on the sand which tends to keep the perforations open. In one well, production is reported to have increased from a daily average of ten or twelve barrels when pumped in the ordinary way to fifty or sixty barrels as now bailed. Disadvantageous are (1) the very fine adjustments required in the electrical operations, and (2) the tendency of bearings in the main drive shaft to overheat during long continuous operation.

The automatic bailer has been used only on comparatively shallow wells, less than 1,200 feet deep. Its use would be limited by the length of time

required to make a complete trip. Experiments show that it is not practicable to increase the speed of the bailer beyond 300 feet per minute so that for deep wells of large production it would not be practical.

J. H. HANCE

Experimental Study of the Invasion of Oil into a Water-wet Sand. By ORREN W. SKIRVIN. Economic Geology, September, 1922. Pp. 461–69.

This article presents the results of several experiments designed to show the manner in which water penetrates oil-wet sand and oil penetrates water-wet sand. Various combinations of sands were used with different grades of oil, and in each case invading water entered the relatively coarser-grained sand more easily than the finer-grained, regardless of the porosities of the two sands used. Oil invading a water-saturated sand body displaced the water from the coarse sand but not from the fine.

From Mr. Skirvin's experiments, it would appear that the occurrence of oil in sands (water-wet) coarser or finer, respectively, than the adjacent strata depends on whether the oil has accumulated by displacing water or whether the oil is a residual fraction retained in the finer-grained portion of a reservoir after displacement by invading water of the oil in the more open portion. "Since commercial deposits of oil usually occur in the most porous parts of a reservoir, we would infer that they have been formed by the displacement of water by oil."

In studying the effects of surface tension on accumulation by using capillary tubes and small glass tubing filled with sand, it was found that while water did not rise in a capillary tube the walls of which were coated with a film of oil, oil did rise normally in a tube the walls of which were wet with water. It is concluded that water-flooding methods for recovery of oil are much less effective with moderately viscous oils than with the lighter, less viscous varieties.

J. H. HANCE

The New Albany Shale of Indiana. By J. R. REEVES. Department of Geology, Indiana University, Serial No. 2390, published by United States Bureau of Mines, 1922.

This is the first of a series of papers on an investigation of Indiana oil shales conducted by the University of Indiana in co-operation with the United States Bureau of Mines, under the direction of Martin J. Gavin, Oil-Shale Technologist of the Bureau.

The New Albany, which is commonly correlated with the Antrim shale of northern Michigan, the Ohio shale of Ohio, and the Chattanooga shale of Kentucky, Tennessee, and Georgia, is the principal oil shale of Indiana. It outcrops over an area of about 500 square miles in Bartholomew, Jackson, Jennings, Scott, Jefferson, Clark, and Floyd counties in southeastern Indiana and also to a lesser extent in White and Carroll counties in northeastern Indiana.

The average thickness of the shale belt in southeastern Indiana is about 50 feet. Favorable location and topographic position of outcrops have permitted inexpensive quarrying, and much of the shale has been successfully used as road material. Except for thin local phases the entire formation consists of oil shale. The fresh shale is hard, brittle, and has a velvety black color but becomes gray and fissile upon weathering. Microscopic examination in thin sections shows resinous spores and spore cases and the abundance of these appears greater in the richer shales.

Analysis of samples showed that oil from the Indiana shale yields a higher percentage of tops than do the oils from the Colorado and Utah shales and that the percentage of unsaturation is less than that of tops from the western shale oils. The amount and composition of the gas produced from the New Albany shale vary with the rate of retorting and the final temperature. Generally 500 to 1,800 cubic feet per ton of shale were obtained, with an average net heating value of 750 British thermal units per cubic foot. Hydrogen sulphide may run as high as 20 per cent of the gas, and the shale averages about .5 per cent nitrogen, a larger quantity than the western oil shales. Conversion of 60 per cent into ammonium sulphate would yield up to 28.3 pounds per ton. Potash occurs as a silicate and varies 4 and 5 per cent (K_2O).

The oil yield from this shale is less than that from western shales and somewhat less than that from Kentucky shale. However, the New Albany shale has the advantageous features of homogeneity, thickness of deposit, quantity available, accessibility, ease and low cost of quarrying and crushing, and high content of nitrogen.

J. H. HANCE

THE ASSOCIATION ROUND TABLE

THE PRESENTATION OF SCIENTIFIC PAPERS

Observation at each of the meetings of this Association, experience at a number of other scientific meetings, and the emphatically expressed opinion of members in our own Association have suggested the desirability of a few lines on the subject of presentation of papers before a scientific society.

All of us who attend the meetings of this or a similar society have much the same experiences. We look forward with anticipation to the renewal of acquaintanceships and the greeting of old friends. We have a good time at the social occasions which are arranged in connection with the meetings. Unlike most conventions, however, it is a peculiarity of scientific societies that chief attention is directed to the technical sessions, where papers are read and discussions are developed. This, to an unusual degree, appears to characterize the American Association of Petroleum Geologists, for comment has frequently been made by visitors on the very large attendance and the sustained interest in the technical sessions of the Association.

It has been suggested, however, that the programs of the Association may be materially increased in interest if the attention of members who read papers at the society meetings is drawn to some of the desirable features in connection with the presentation of their papers. We are all anxious, in delivering our papers, to present clearly to our listeners the subject of our contribution, to direct main attention to the points of greatest importance, to inspire confidence in our treatment of the subject, and to carry conviction in our conclusions. We wish to be heard distinctly and easily by all who are in the room, and to appear before our audience without awkwardness in manner or speech.

With these aims in mind, and thinking by way of contrast of the discomforts we endured when friend "So-and-So" was presenting his paper, let us consider the problem with reference to our proposed appearance on the program at the next meeting. In the first place, should the paper which we have prepared be offered in exactly its present written form at the meeting of the Association? Our paper contains all of the pertinent data which belong to our investigation just as they will appear in the *Bulletin*, in which place they will be available for study by any member of the Association or other readers. Remembering that the detailed statements of stratigraphic features which, in some cases at the last meeting, were read at length, were not essential at the time to our understanding of the paper, and with reminiscences of our lack of interest in some of these things, would it not be well for us in our own paper to prepare a suitable chart or lantern slide which will show to the

Association without loss of time or interest this aspect of our subject? The details will be published later. What are really the essential points in our paper? How can we present these points most clearly and briefly to our hearers? So far as the meeting is concerned, it would seem evident that it is not necessary to include in our presentation a number of things which, nevertheless, should appear in the printed article. Let us omit these or summarize them. Our paper will be interesting and valuable at the meeting in proportion as it covers clearly the essential points in a brief time and brings forth a maximum of worthwhile discussion.

It will be desirable for us to prepare illustrations for our paper, if that is possible, for it will make parts of our paper much clearer to our associates. Rather preferably these should be lantern slides, for it is fairly sure that these will not be too small to be seen clearly by those in the room, and we will avoid the difficulty and delay of putting up charts, especially if there are a number of them. In any case, our chart should be clearly legible in a large room.

Finally, we should be sure that our voice is sufficiently loud and our words sufficiently distinct to be heard without difficulty, even if there are minor disturbances in the room.

To most of us in the American Association of Petroleum Geologists it seems desirable to avoid, if possible, the practice of repeated subdivision of our program into sections. It is impossible to be in more than one sectional meeting at a time, and one must choose a comparatively small number of papers which he specially wishes to hear. The simultaneous reading of long papers to relatively small groups in a number of separate meeting places is objectionable unless the subject-matter is so extremely specialized as to interest only various sorts of specialists. In our Association we are all oil geologists and no such lines of differentiation exist. Therefore, we prefer to stay together. Unless, however, thought is directed to the subject-matter of our papers read before such general sessions, and to the manner of our presentation, it will be increasingly difficult to realize the benefits which we all desire in our meetings. Let us endeavor to shape things so that, while covering a large number of interesting papers, we will provide for maximum consideration and discussion, in the meetings, of the subjects offered.

RAYMOND C. MOORE

"FOR REVIEWERS"

By H. S. CANBY, *Literary Review*, January 6, 1923[1]

Any geologist who contemplates either writing a review or even reviewing a book without discussing it may profit by studying the editorial mentioned above, for although Mr. Canby may not have had reviews of scientific papers

[1] This contribution, though submitted as a review, is placed in the Association Round Table.—EDITOR.

in mind, he unquestionably touches sore spots that disfigure many such contributions, and gives a concise idea of things that a review should and should not contain, and motives that should and should not inspire a reviewer.

He says in part: "Whatever else a review does, it *must* make clear the nature of the book reviewed. It must define, explain, as well as criticize. No matter how brilliantly written, no matter how instructive otherwise, a review that fails to tell the reader what the book is like is itself a failure." A criticism is not a review, although it is commonly a part of the best reviews. Indeed, as Canby states, "A review *must* be critical," which is a very different thing from saying that a reviewer must criticize. It takes a critical review to show that there is nothing to criticize in a good piece of work, as well as to bring out the weaknesses and point out the improvements needed in a poor piece of writing.

"A review must be sympathetic. This does not mean that it should be favorable or kindly. . . . . It is the business of the reviewer to penetrate to the very purpose and scope of the author, and this can be done only by sympathy; then let him accuse or praise, as his discovery justifies."

Finally, and most emphatically: "A review must have no ulterior aim, as the praise of friends or the pricking of enemies,—tooting, puffing, chastising, or backbiting—that is the unpardonable sin in reviewing." In other words, do not review a work because you dislike the author and it gives you a chance to advertise his errors, expose his shortcomings, or exercise your gift for sarcasm. Do not use a review to magnify the excellence and bury the mistakes of a friend's writing. Above all, do not write a review just to show that you are a little smarter than the other fellow, getting the hot air to float your balloon from the fire you light under some unfortunate victim.

K. C. HEALD

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

GEORGE OTIS SMITH resigned as director of the United States Geological Survey to become a member of the Coal Commission.

DAVID WHITE resigned as chief geologist of the United States Geological Survey in November to devote his time to geological research.

J. O. LEWIS has opened an office at 742 Kennedy Building, Tulsa, for the firm of Smith, Dunn and Lewis, and will make his headquarters in Tulsa.

A. W. DUSTON is in consulting practice at Okmulgee.

PAUL RUEDEMANN is now located at 505 Atlas Building, Tulsa.

G. L. ELLIS spent the summer in northern Mexico for Snowden-McSweeny.

VERNON H. WOOLSEY, now with the Atlantic Oil Producing Co., first mapped the surface structure at Luling, Texas, where the Rios oil well was drilled.

W. B. WILSON has lately been made chief geologist of the Gypsy Oil Co., with office at Tulsa.

A. E. FATH is in Poland.

W. L. LONGMIRE is district geologist of the Gypsy Oil Co., at Ponca City, Oklahoma.

E. G. WOODRUFF spent the fall in the San Juan Basin, southeastern Utah.

A. S. HENLEY is chief geologist of the Houston Oil Co., in Houston, Texas.

W. A. J. M. VAN WATERSCHOOT VAN DER GRACHT is now associated with the Marland Refining Co.

HARRY BROWN is chief geologist of the Pierce Oil Corporation, with his office in Tulsa at 1111 South Elgin Ave.

EDDIE HYDE is representing the Marland Refining Co. in southeastern Texas.

ROBERT DOTT is with the Carter Oil Co.

L. W. KESLER is with the Sinclair Oil and Gas Co. of Tulsa.

C. V. MILLIKAN is now with the Amerada Petroleum Corporation at Tulsa.

HARPER MCKEE of New York has been working in West Virginia.

STANLEY C. HEROLD is spending the winter in New York City.

CHARLES R. ECKES returned to South America in January after visits to London, New York, and Tulsa.

E. DE GOLYER spent January in London.

ARTHUR EATON plans to open an office in San Francisco.

LUCIAN WALKER, who has spent several years in China, expects to return to the United States this summer.

D. R. SEMMES, of Tampico, made a trip to New York in January.

JAMES H. GARDNER has spudded in his test near Schoolton, Oklahoma.

H. B. GOODRICH has been doing some work in the Tri-State lead-zinc area.

The officers of the Tulsa Geological Society for 1923 are: President, Richard Hughes; Vice-President, J. C. Ross; Secretary, E. F. Shea; Treasurer, George A. Kroenlein.

SIDNEY POWERS and JAMES H. GARDNER of Tulsa attended the meeting of the Geological Society of America at Ann Arbor, Michigan.

RUSSELL S. TARR has been devoting his attention to Kansas during December and January.

H. W. BELL and C. O. RISON have published *Notes on the Smackover Field, Arkansas*, in mimeographed form, as a contribution of the United States Bureau of Mines.

W. R. HAMILTON, of Tulsa, spent January in New York.

FRANK A. EDSON has resigned from the United States Bureau of Mines to organize a company for the drilling of oil wells with the diamond drill.

The new well at Powell, Texas, is located on the Powell dome, mapped by GEORGE C. MATSON and O. B. HOPKINS several years ago for the United States Geological Survey.

R. J. RIGGS has resigned from the Dixie Oil and Gas Co. to accept a position with the Freeborn Engineering Corp. of Tulsa.

J. W. MERRITT has resigned from the F. W. Freeborn Engineering Corporation to do consulting work, with headquarters at 1324 East Seventeenth Place, Tulsa.

M. E. WILSON, of the Invincible Oil Co., is moving to Shreveport, to take charge of the geological work of the Louisiana Oil and Refining Co.

FRANK BUTTRAM, WILLARD MILLER, D. J. EDSON, R. B. WHITEHEAD, D. S. HAGER, ANGUS MCLEOD, F. H. LAHEE, E. RUSSELL LLOYD, C. J. WOHLFORD, and R. D. GOODRICH have been watching the new well at Powell, Texas.

H. G. OFFICER is working in Texas.

C. W. HONESS, of the Oklahoma Geological Survey, has presented the results of his several seasons' work in the Ouachita Mountains of southeastern Oklahoma in the form of papers given before the Tulsa and Okmulgee Geological societies.

DR. JOHAN A. UDDEN, state geologist of Texas, visited his son, Jon A. Udden, in Tulsa, en route to the Ann Arbor meeting of the Geological Society of America. While in Tulsa, Dr. Udden addressed the Mid-Continent Section of the American Institute of Mining and Metallurgical Engineers on "Some Geological Problems."

W. C. MENDENHALL has succeeded David White as chief geologist of the United States Geological Survey.

During the absence of George Otis Smith on the Coal Commission, PHILIP S. SMITH is acting director of the United States Geological Survey.

LOUIS ROARK has resigned as president of the Okmulgee Geological Society and C. A. WARNER has been elected to the position.

GEORGE È. BURTON has recently resigned his position with the Roxana Petroleum Corporation, in St. Louis, and has established consultation work at 40 Sylvester Avenue, Webster Groves, Missouri.

H. J. ALLEN and MARVIN LEE, consulting geologists at Wichita, Kansas, have recently perfected an interesting invention, an oil-burner, which appears to mark a considerable improvement on burners now in general use. This burner is to be manufactured and sold at Wichita.

PROFESSOR H. V. HOWE is the new head of the Department of Geology at the Louisiana State University, at Baton Rouge.

W. L. WALKER is Chief Geologist and Manager of the Land Department of the Pierce Oil Corporation. Harry J. Brown, geologist associated with Mr. Walker, was erroneously mentioned as Chief Geologist of the Pierce, in a recent number of the *Bulletin*.

HERBERT N. WITT now has offices at 512 Sharon Building, San Francisco, California.

ROBERT B. BOSSLER, F. ARTHUR JOHNSON, and N. W. SHIARELLA are now associated in consulting work, with offices at Sheffield, Pennsylvania. They have taken over management of the Anchor Oil and Gas Company, with properties in Pennsylvania.

LEON J. PEPPERBURG, consulting geologist at Dallas, has recently been instrumental in securing a test south of Ivan, Stephens County, Texas, which discovered important new deep production at about 3,900 feet. Wells drilled to the deep pay in this territory are now reported at from 500 to 1,000 barrels of 40 gravity oil.

CHRISTIAN VRANG has opened a consulting office in Rock Springs, Wyoming, in connection with his Salt Lake City office.

D. DALE CONDIT, Chief Geologist of the Indian Branch, Whitehall Petroleum Corporation, Ltd., has returned to India. His headquarters are in Calcutta and mail will always reach him there if sent in care of the Alliance Bank.

W. C. MORSE, F. E. VESTAL, and ten students of the Mississippi Agricultural and Mechanical College recently completed a very interesting geological field trip in the Appalachians and adjacent region. The party traveled in two specially designed 1-ton Ford trucks and covered about 2,000 miles.

THE ROCKY MOUNTAIN ASSOCIATION OF PETROLEUM GEOLOGISTS held its annual election on December 21 at the Albany Hotel, Denver, and elected the following officers: President, C. A. Fisher; First Vice-President, Thomas S. Harrison; Second Vice-President, Dean E. Winchester; Secretary-Treasurer, Charles M. Rath. The new officers assumed their duties at the meeting on January 4.

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